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# THE POTENTIAL OF AUTOMATED TRANSPORT SYSTEMS IN THE FUTURE OF URBAN MOBILITY

IAV - UPC

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By

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## Abstract

Global warming is endangering the earth as we know it, and CO<sub>2</sub> levels are rising to amounts the world has never seen before and cannot handle. Additionally fossil fuels and natural resources are depleting very rapidly. For that reason the 1997 Kyoto protocol up to the 2018 Paris Agreement were signed, aiming towards a more sustainable and environmentally friendly resource extraction and reduction of the CO<sub>2</sub> footprint. Introducing Smart, emission free cities, is one of the solutions to this challenge. To develop such a city, all day to day activities must be considered. This includes but is not limited to: communication, electricity and mobility. These factors are in the bigger picture connected and will be introduced through analyzing future mobility in this thesis.

Mobility plays a big role in maintaining the stability of the grid, expected to be supporting the unpredictable renewable energy sources through charging and discharging when needed. This will play a big factor for Demand Side Management and enable a better, higher quality of life. Future vehicles are expected to be electrical and autonomous, requiring no human interaction during the driving. They should be a part of a bigger system, allowing all the city's residents to be able to get from A to B safely and efficiently. Allowing on the city to become more self sufficient and sustainable and on the other hand easier connection to neighbouring cities. The future resident will not have to worry about getting from a place to the other, even if its in a rural area. The beauty of having such a system enables worry free mobility for the citizen and a structured design for the governments.

The potential of these autonomous vehicles is analysed on a techno-economical base and their implementation is simulated on a virtual residential quarter in Berlin, Germany. The technical simulation works intelligently, creating iterations to provide the best possible way and the amount of vehicles needed. Whereas the economical analysis shows the potential of the autonomous vehicle with regards to value and money.

The potential of autonomous vehicles as means of mobility in Smart Cities will be conveyed in this master thesis, clearly showing the benefits if such a system were adapted.

## Contents

<b>Executive Summary</b>	<b>6</b>
<b>Glossary</b>	<b>7</b>
<b>1 Introduction</b>	<b>8</b>
1.1 Smart Cities general introduction . . . . .	8
1.2 Smart Mobility . . . . .	10
1.3 Cooperation research project-PAVE Introduction . . . . .	12
1.4 Scope of the project and project's objectives . . . . .	14
1.5 Thesis structure . . . . .	15
<b>2 Transportation in urban cities today</b>	<b>16</b>
2.1 State of the Art EVs . . . . .	16
2.2 State of the Art Car-sharing . . . . .	22
2.3 State of the Art autonomous EVs . . . . .	28
<b>3 Smart Cities</b>	<b>33</b>
3.1 Smart Cities goals . . . . .	33
3.2 Possible Scenarios . . . . .	33
3.2.1 Business as usual (Base line) . . . . .	34
3.2.2 Policies towards sustainability . . . . .	34
3.2.3 Policies and Demand Side Management . . . . .	35
<b>4 The City of Berlin</b>	<b>36</b>
4.1 General Introduction . . . . .	36
4.2 Transportation in Berlin today . . . . .	38
4.3 Berlin expanding residential areas . . . . .	39
<b>5 Case study</b>	<b>41</b>
5.1 The Location . . . . .	41
5.2 Technical Analysis . . . . .	43
5.2.1 The Coordinates Network . . . . .	43
5.2.1.1 Network Code . . . . .	48
5.2.2 The Population . . . . .	50
5.2.2.1 Population Code . . . . .	54
5.2.3 Configuration . . . . .	56
<b>6 Results</b>	<b>59</b>
6.1 The Technical Potential . . . . .	59

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6.2	The Economical Potential . . . . .	61
6.3	The Environmental Potential . . . . .	63
7	Conclusion	64
8	Future work	65
	Bibliography	66
A	Configuration Code :	71
B	Network Code :	74
C	Plans Code :	79



## List of Figures

1	Pillars of a Smart City (Own graph) . . . . .	10
2	Private and Public Transportation (Own graph) . . . . .	11
3	PAVE scenarios . . . . .	12
4	System Lohner Porsche - La Toujours-Contente [10] . . . . .	16
5	Tesla Roadster (997 km range) [16] . . . . .	18
6	Electrical block diagram of an EV [18] . . . . .	19
7	Scheme of an AC and a DC charging station [20] . . . . .	19
8	IEC standardized 62196-1 . . . . .	20
9	Plug Types [21] . . . . .	20
10	The first E-Highway in Germany [22] . . . . .	21
11	CO2 generation [23] . . . . .	21
12	Uses of Car-sharing . . . . .	22
13	Global Car-sharing map [27] . . . . .	23
14	Car-sharing success landscape [28] . . . . .	24
15	European Car-sharing trends [29] . . . . .	25
16	Human vs. Autonomous driving . . . . .	28
17	Different sizes and purposes of vehicles in different locations [43] . . . . .	31
18	Hamburg Electric Autonomous Transportation [44] . . . . .	32
19	Map of Berlin [49] . . . . .	36
20	Map of Berlin 1946 [52] . . . . .	37
21	Train lines in Berlin [55] . . . . .	39
22	New residential areas in Berlin [58] . . . . .	40
23	Gartenfeld on Google maps . . . . .	42
24	Gartenfeld's architectural plan [60] . . . . .	43
25	3 Different routes for the vehicles . . . . .	44
26	Vehicles lines in Gartenfeld . . . . .	45
27	Nodes and Lines . . . . .	46
28	Pink nodes code . . . . .	48
29	Pink links code . . . . .	49
30	Linestops . . . . .	50
31	Population code . . . . .	55
32	Configuration code . . . . .	57
33	Final result MATSim viewed in VIA . . . . .	58
34	Load shifting vs Peak shaving [63] . . . . .	59
35	EV storage and electrical demand [64] . . . . .	60
36	CO2 targets [22] . . . . .	63

## List of Tables

1	Levels of vehicles charging [18][17] . . . . .	18
2	Urban quarters [30] . . . . .	25
3	Car-sharing overview in Germany 2019 [32][33][34][35] . . . . .	26
4	Lines information . . . . .	30
5	BAU scenario . . . . .	34
6	Policies scenario -strict . . . . .	34
7	Policies and Demand Side Management scenario . . . . .	35
8	Urban quarters [59] . . . . .	41
9	Overview new nodes and links . . . . .	47
10	Overview pink line . . . . .	48
11	Gartenfeld residents, workers and visitors per day . . . . .	50
12	Distribution of Gartenfeld residents, workers and visitors . . . . .	51
13	Gartenfeld residents, workers and visitors per day . . . . .	52
14	Gartenfeld residents, workers and visitors per day . . . . .	52
15	Amount of line stops users . . . . .	53
16	Total users . . . . .	53
17	Total users . . . . .	54
18	Lines information . . . . .	61
19	Capital cost comparison . . . . .	61
20	Variable cost comparison . . . . .	62
21	Variable cost comparison . . . . .	62

## Executive Summary

With the rise of technology in the world and the demand for a smarter life, the transportation system infrastructure is expected to change completely. It is expected to be able to support the electrical grid, enable communication and allow for easier more rapid mobility to longer distances. For that reason the economical, technical and environmental potential of autonomous vehicles is shown and analyzed in this thesis in Chapter 5 and Chapter 6.

The urban quarter chosen to simulate is Gartenfeld located in Berlin, Germany. This quarter is being newly built as a residential area after having been an industrial area shown in Chapter 4. The autonomous vehicles used are considered to be a part of the public transportation system in charge of connecting the residents and guests of Gartenfeld to the closest railway station. These vehicles are expected to be completely autonomous and do not require any direct human interference during the drive. The autonomous vehicles, which are developed by the IAV are called HEAT, they can drive up to 50 km/h and will transport up to 16 people at once, as can be seen in Chapter 2. Two different scenarios are shown, one for the summer days and one for the winter days. These scenarios allow for more flexibility regarding the need and use of the vehicles. The vehicles should completely eliminate the use of personal vehicles as well as busses and Taxis. It should also substitute goods delivery trucks for small to medium size deliveries. Gartenfeld's streets and residents are simulated virtually based on statistics and propositions based on expectations. The vehicle routes and use are programmed in csv form. These are then added to a public transport schedule on MATSim (Multi-Agent Transport Simulation) together with a configuration code. This simulation optimizes the transport mode after a defined amount of iteration and sets the needed parameters.

Along with the technical simulation an economical analysis is done, analyzing the potential of the HEAT vehicles on a regional and population base. The initial investment's fixed cost as well as the variable cost is discussed. The labour needs and the complete operations plan of the vehicles is introduced and optimized according to the needs of Gartenfeld.

Lastly the the complete techno-economical analysis is discussed explaining the need of Demand Side Management and the effect of this system on the electrical grid. Gartenfeld is presented as a smart transportation city, visualizing the huge potential of autonomous vehicles.

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## Glossary

### Abbreviations

**AC** Alternating Current

**BVG** (Berliner Verkehrsbetriebe Gesellschaft) **Berlin transportation company**

**DB** (Deutsche Bahn) **German railway company**

**DC** Direct Current

**DSM** Demand Side Management

**EV** Electric Vehicle

**HEAT** Hamburg Electric Autonomous Transportation

**IoT** Internet of Things

**MaaS** Mobility as a service

**S-Bahn** (Stadtschnellbahn) **city rapid railway**

**U-Bahn** (Untergrundbahn) **city underground railway**

# 1 Introduction

## 1.1 Smart Cities general introduction

A trend around the term *Smart* has been going on for the last decade. *Smart* Phones, *Smart* Homes, and *Smart* Cities are considered the future standard. These words are often heard alongside abbreviations such as IoT, 5G and DSM. However these complicated small words have been around since the start of civilization. The terms *Digital* City, *Knowledge* City and *Green* City were indicative of the ambition of these different eras [1].

Nowadays, people expect a lot from technology and have made their quality of life dependent on it. This is the result of the technological outbreak that started in the twentieth century and made material possessions a bare necessity. At the start of this movement, electricity generation was no challenge since cheap coal, gas and oil were available to burn in large amounts [2]. This is when two main problems arose, forcing the world to look for alternative resources. The first of which is the depletion of natural resources, which is occurring at an unknown speed. This is exemplified by Hubbert's peak theory, which posits that petroleum production tends to follow a bell-shaped curve [3]. Although once considered the most accurate depletion estimation, it does not take two very important factors in consideration. Firstly, the fact that the price of oil is dependent on both the economical equilibrium of supply and demand and the often unpredictable political situation as a consequence is not imported in a constant quantity [4]. Furthermore the new resources that could be found unexpectedly, such as the shale gas boom in the United States in 2014 [5]. These factors forced the industrialized countries, specifically members of the European Union and neighbouring countries to look for natural resources and develop a better, safer and cleaner generation system. One which does no harm to the environment while meeting local energy requirements.

The Smart European city therefore has to take all factors in consideration, specifically ones which directly affect the citizen's daily routine.

For that reason, one of the infrastructures that will significantly change in the upcoming era, is the transportation system. The era of *Smart* Mobility started with the first version of Mobility as a Service (MaaS) that penetrated the developed metropolis. These usually offer a fleet of shared electric vehicles in exchange for a price per minute and allow the user to enjoy a lot of flexibility for a little responsibility. In the future, this concept is expected to take over with an autonomous feature. This means, they will not need a driver to get from point A to B, but rather do that automatically, in a comfortable and efficient manner. The futuristic infrastructure of autonomous vehicles considers more safety measures, a self charging system and most importantly a citizen's acceptance analysis.

In this thesis the potential of autonomous vehicles is presented and analyzed in a specific quarter in Berlin, Germany. The following objectives are to be realised:

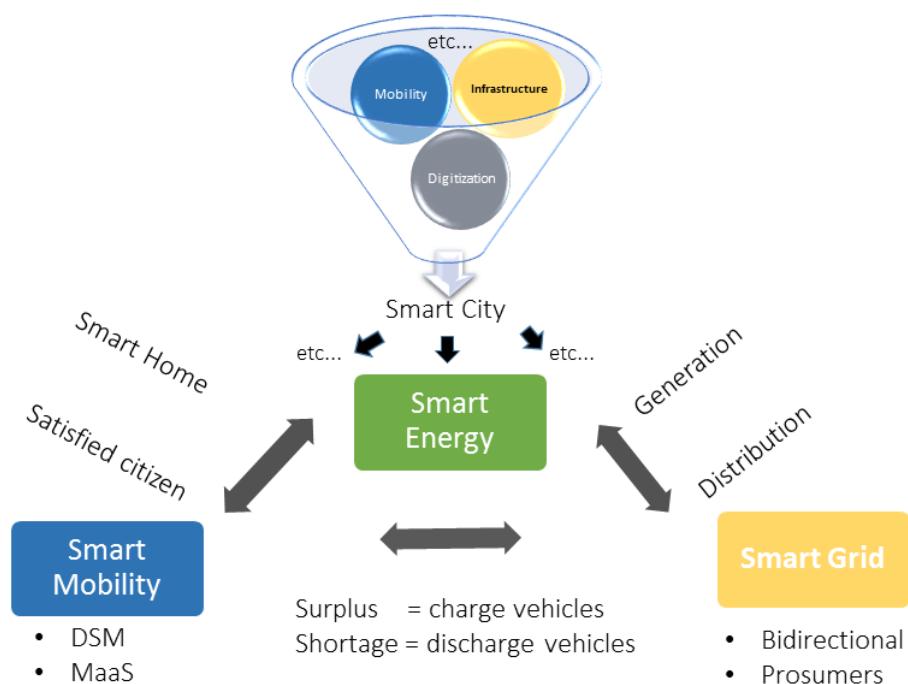
- Technical potential: How can the vehicles help the electrical grid
- Economical potential: How much cost reduction can be achieved
- Environmental potential: How much CO<sub>2</sub> reduction is achieved in comparison to existing systems and their emission.

These are to be expressed in words and numbers with the help of a MATSim simulation to further realise the system realistically.

## 1.2 Smart Mobility

Smart Mobility is an important pillar to attain a Smart City. Figure 1 shows the role of Smart Mobility and how the structure could be visualized. Here the funnel includes the main issues to be reconfigured in order to ensure a proper transformation, which includes mobility. If all of these are considered and upgraded properly, a Smart City is built. However a Smart City infrastructure is a bit more complex and includes different build stones. One of which is Smart Energy.

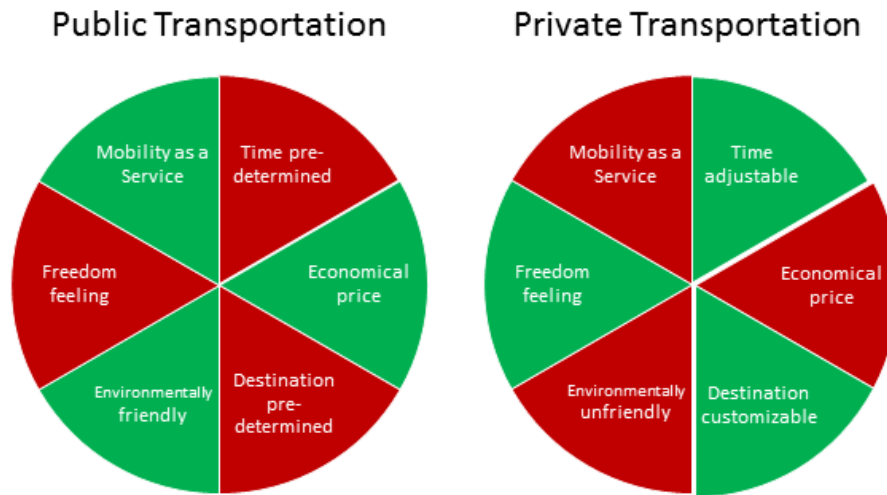
The process starts with the smart renewable generation of energy, which is distributed via the Smart Grid. This grid should be bidirectional in order to enable the easy flow to and from consumers who are also producers. When there is an excess of energy, the electric vehicles are to be charged and discharged when there is a shortage of energy. This creates a direct connection from the Smart Grid to Smart Mobility. Enabling Demand Side Management and Mobility as a service are two of the main points that Smart Mobility supports. This ensures having a satisfied customer with a properly designed Smart Home in a Smart City.



**Figure 1:** Pillars of a Smart City (Own graph)

Nowadays, Smart Mobility is associated with autonomous (driver-less) electrical vehicles. These will most likely be shared inside a city and be able to react to digital calling, for instance through an application. This new traffic infrastructure will have a big impact all of these cities that apply it and design their infrastructure around it.

According to a McKinsey study, more than 1% of a country's GDP is negatively impacted by traffic congestion [6]. Shared autonomous vehicles are expected to ease this congestion and eliminate 9 out of 10 privately owned cars in a medium sized European city [7]. This would free up a lot of space on existing roads and require much fewer parking spots. For citizens, this might mean more green space and leisure areas. Furthermore, providing shared autonomous vehicles will increase safety levels and reduce the cost of transportation. This is done by combining the positive features of public and private transportation today into one driver-less fleet of vehicles providing the same service.



**Figure 2:** Private and Public Transportation (Own graph)

As can be seen in Figure 2 above, six different features are examined in the public and the private transportation system. The green fields demonstrate a positive analysis whereas red fields show a negative evaluation. Accordingly Smart Mobility should provide customers with the public transportation's economical prices, and environmental friendliness, while offering Mobility as a Service. Additionally they are expected to be time flexible, have more flexible stops and give the customer a feeling of freedom, similar to the private transportation system today.

An example of how such a system could be designed for the future of Smart Mobility can be found in [subsection 3.1](#). The potential and analysis of such a system is to be analyzed throughout this thesis.



### 1.3 Cooperation research project-PAVE Introduction

A research project made up of a group of Berlin based traffic and transportation experts regarding the future of autonomous vehicles was established around 2017. The name PAVE comes from the German: "Potentiale Automatisierter Verkehrssysteme" which can be translated to "Potential of autonomous transport systems". The council's foundation is made up from experts with different expertise to challenge each other and come up with the best possible outcome. The automotive expert IAV GmbH, together with the technical experts from Robert Bosch GmbH represent the technical aspect for the research project. The Technical University of Berlin and the Otto-von-Guericke University of Magdeburg represent the research aspect and simulate both the technical and the economical aspect. Car sharing experts such as Door2Door GmbH and Daimler AG speak for the automotive customers. Adding to that the E.R.P. (Eastern Relationship Projectconsult and Real Estate GmbH) and the INA (Berlin's International Academy for innovative pedagogy, psychology and economics) offer a broad overview for the topic to be researched.

Together they came up with five different scenarios and assigned possible outcomes. These were then divided in different categories and analyzed in the group. For each scenario, different use cases and probabilities assuming the current situation were determined and evaluated.

	Status Quo Restriktive	The nice individual scenario	Q traffic	The nice collective scenario	AVFIV The mixed scenario	
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Environment
Business models passenger traffic	1 public transport	2 everyone rides	1 public transport	2 everyone rides	2 everyone rides	economy
Business models heavy transport	1 SME offer vehicles	2 capital Enterprise	2 capital Enterprise	2 capital Enterprise	1 SME offer vehicles	economy
Passenger's mobility needs	2 collective	1 individual	1 individual	2 collective	1 individual	society
Good's mobility needs	2 cost	1 quality	2 cost	2 cost	2 cost	economy
Municipal control measures	2 solid control	2 solid control	1 Status Quo	2 solid control	2 solid control	urban regulation
Logistics concepts for light transport	1 packing station	2 drones	1 packing station	1 packing station	1 packing station	economy
Regulatory usage restrictions	1 restrictive	2 concession for all	1 restrictive	2 concession for all	1 restrictive	urban regulation
Authorization of technologies	1 restrictive	2 type approval	2 type approval	2 type approval	2 type approval	politics
Available technologies	1 elementary	2 technical availability	2 technical availability	2 technical availability	2 technical availability	technology
Multi-Use vehicles	1 separation	2 multi use	1 separation	2 multi use	1 separation	economy /technology
Acceptance of self-driving vehicles	1 rejection	2 acceptance	1 rejection	2 acceptance	2 acceptance	society
Transportation policy goals	2 Status Quo	1 progressive	2 Status Quo	1 progressive	1 progressive	politics
Cost of private and shared rides	1 economical rides	1 economical rides	2 high cost	1 economical rides	2 high cost	society /economy
Intelligent traffic control and infrastructure	1 missing standards	2 networking	2 networking	2 networking	2 networking	urban regulation
Labour market	1 weak development	2 prosperous	2 prosperous	2 prosperous	2 prosperous	society /economy
Urbanization	1 unmodified	2 suburbanization	1 unmodified	2 suburbanization	2 suburbanization	urban regulation
PV demand induced by new technologies	1 moderate	2 strong increase	1 moderate	2 strong increase	2 strong increase	technology/economy/society
KEP demand induced by new technologies	1 moderate	2 increase	2 increase	1 moderate	1 moderate	technology/economy/society
Economy						
Society						
Urban Regulation						
Politics						
Technology						
Ecology						

Figure 3: PAVE scenarios

In the above Figure 3 the broad overview is represented.

Each scenario does not foresee the future but rather try to speculate what might happen in order to prepare for the consequences. Scenario 2 and scenario 3 here represent two different ways of future transportation. Both eliminate the use of private vehicles and assume the provided autonomous vehicles to belong to the transportation provider in the city. Whether this provider will be the existing DB or BVG or an entirely different provider does not matter at this point. The only point to keep in mind is that these vehicles will not belong to an individual and will be offered as MaaS. This allows the residents to use the vehicle fleet as a way to transport from point A to point B.

Both scenarios allow everyone to ride the vehicles, handle residents mobility needs individually and are technically feasible. However, the second scenario considers the vehicles to be used individually bringing the passenger from door to door. This scenario expects residents to be able to order a vehicle at any time and the vehicle to drive to the user at the requested location. These vehicles will only carry one family or one party at a time. Allowing them to use the vehicle privately and without any restrictions. This scenario offers its passengers privacy and an unbeatable service. But it would not necessarily help reduce the traffic and is expected to be at a very high cost.

On the other hand, the fourth scenario compares the vehicles to shared buses or existing shared car rides. It expect each individual to share the route with at least another individual going in the same direction. It could offer a door to door service, or define specific pick up and drop off locations, similar to a bus. According to study done in Lisbon, this system is expected to eliminate nine out of ten cars on the streets today. Allowing only one car to do the job of all ten cars, hence reducing the parking spaces needed and allowing cities to be greener [8]. This scenario offers residents no privacy and thus could reduce some residents expected quality of life. But it does help the environment and the restructuring of the transportation infrastructure to match the Smart Cities level. For that reason this scenario will be adapted in this thesis, offering a possible outlook for an exclusive service for people who would rather drive individually.

## 1.4 Scope of the project and project's objectives

The future of mobility is a very sensitive topic that is being viewed and analyzed in very different ways by experts of the field. Germany, being one of the leading car manufacturing countries if not the leader, is surprisingly unclear on the vehicle's future.

It is indeed true, that if the production of combustion engines would stop today, the world's economy would collapse. However, the United States, France and China seem to believe that the future of mobility is electric i.e. e-Mobility. These countries have companies such as Tesla, Peugeot and various Chinese companies making significant progress in regards to the to promoting the advancement of electric vehicles. Whereas the German top manufactures, who would be expected to be the world's leading companies, are still behind. Their management seems to have a conflict between leaving things as they are and developing towards hybrid and electric vehicles.

This is no surprise, since the German culture seems to be resisting digitization. This can be seen on a daily basis, since paying in cash and buying the bus tickets from the driver is a normal way of living. In this aspect a leading country, such as Germany, seems to be even behind developing countries. Public policy seems to be aligning with the people's wishes and not introducing digitization friendly policies. According to Kai-Fu Lee [9], digitization and artificial intelligence (AI) will continue to be major factors impacting the future of human civilization. Mentioning AI is specifically important because it is imminent for the expected overtaking of autonomous vehicles.

In this thesis, the potential of autonomous vehicles in a specific urban quarter will be analyzed on different levels. The economical, environmental and technical potential will be very beneficial but the mindset of Germans as well as the resulting unemployment must be considered.

A simulation will be programmed to show the exact flow of the vehicles and visually show the benefits of not having 9 out of the 10 cars currently on the streets. Furthermore the 75% cost reduction that will occur and the resulting the elimination of human drivers will be taken into consideration to calculate the financial cost benefit analysis. A humane view must be considered to avoid possible catastrophic events resulting from this unemployment and this must be included in future plans. Politics and public policy will not be considered in this thesis, as they are neither AI nor autonomous friendly and will therefore have to change greatly. The policies are hindered by two specific factors: privacy and liability. These hinder both the data collection and a the potential for a driver-less vehicle. Both elements are crucial for the adaption of this thesis.

Ethically speaking such a project might put a number of people out of job. However with the rise of BVG drivers strikes and the rise of Smart City, such a a fleet could be a cities solution to a lot of challenges. Enabling both easier transportation to hard to reach zones and a fluid mobility within cities.

## 1.5 Thesis structure

This thesis is structured to firstly introduce Smart Cities and zoom into one of it's pillars, Smart Mobility. After which the project's objectives are explained after viewing a similar model in Chapter 1.

Chapter 2 explains the evolution and development of Electric Vehicles and gives an overview of the state of the Art of these vehicles. It explains how autonomous cars were introduced and their levels of autonomy.

The topic Smart Cities is then discussed more thoroughly, explaining its necessity based on possible out coming scenarios in 3.

To design a transportation system and test the potential of autonomous vehicle, a city is chosen to simulate it. This city is Berlin, which is introduced in 4 together with its transportation infrastructure.

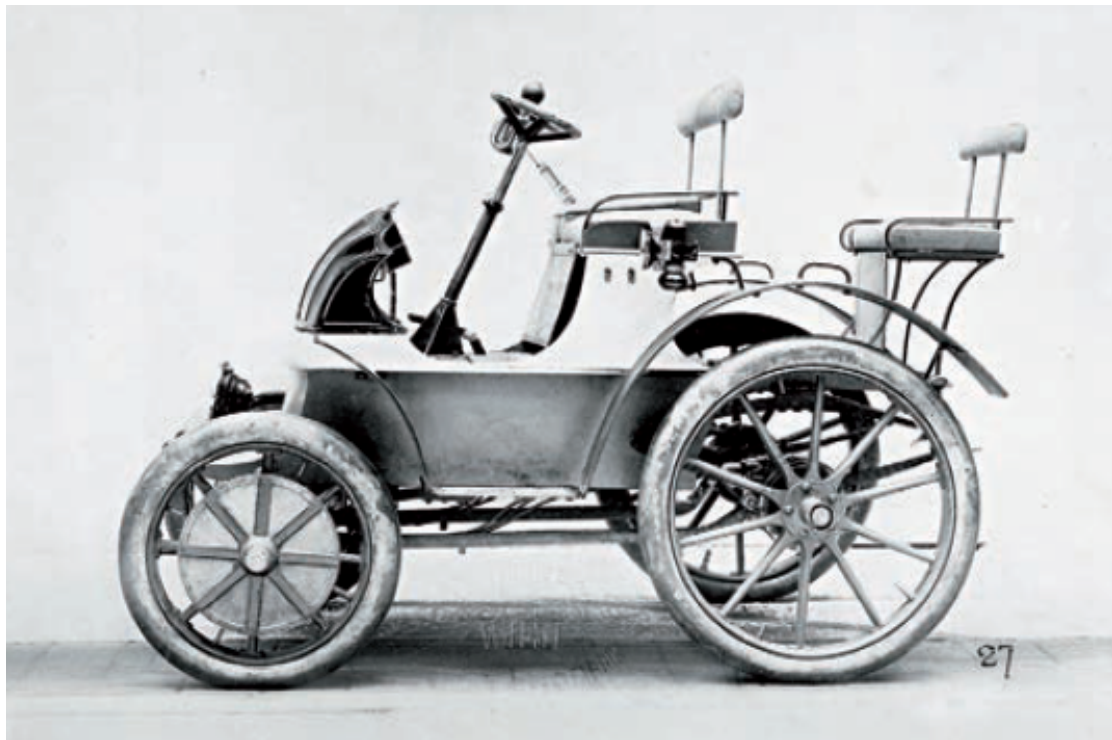
Understanding that Berlin is a huge city, the focus is decided to be on a specific urban quarter, Gartenfeld. This was chosen under the hypothesis, that it is easier to create a habit than to change one. A complete technical analysis is made with MATSim, where a model of the future quarter is simulated in Chapter 5.

Based on this, a techno-economical-environmental potential could be extracted, showing the potential of such a system in real life in 6. This is followed by a Conclusion in Chapter 7 and suggestions for Future Work in 8.

## 2 Transportation in urban cities today

### 2.1 State of the Art EVs

The term "electric vehicles" has been known since the turn of the 19th century. In fact, Ferdinand Porsche presented his electric vehicle "La Toujours-Contente" in the 1900 Paris World Exhibition. The idea was simple: use electricity stored in a battery to fuel the vehicle. However, back then power electronics' components as we know them today were not introduced. As a result, the batteries had to be enormous and the charging time was very long. These factors made the electric vehicle much less popular than the combustion driven vehicles [10]. The following years, the chemistry composition and the electronics of the battery were rethought and the battery was reshaped.



**Figure 4:** System Lohner Porsche - La Toujours-Contente [10]

The German National Platform for Electric Mobility (NPE) was founded in 2009 to help pursue the fossil free mobility in Germany. The group of 150 representatives from various sectors established a target to pursue electric mobility. After having analyzed the market, they concluded that one million electric vehicles by 2020 is realistic [11].

In order for this vision to become a reality, a lot of work must be done on the most crucial component of the electric vehicle, the battery. Unlike hybrid cars, which are able to run on both fossil fuel and the battery power. Or the fuel cell hybrid electric vehicle, which is able to chemically convert Hydrogen to move the vehicle. Battery Electric vehicles sole source of power is the electrically charged battery. Battery Electric Vehicles (BEV) can only drive for up to 200km (Tesla 450km) at once and needs several hours to recharge the battery. BEVs are therefore perfectly suitable for short distances inside a city with multiple charging locations [10]. The Range Extended Electric Vehicle (REEV) is the upgrade of the BEV in relation to the battery capacity, thus the range of travel. REEVs are expected to be the cars to be privately owned and cared for, since they overcome the recharge time limitations and are more comfortable for the private use [10], [12].

The art of designing and maintaining a satisfying car battery is still considered one of the world's biggest challenges. This is a result to the defined norms of owning and charging a vehicle. Nowadays one does not need more than 10 minutes to refuel, pay and leave the gas station not having to worry about the next fueling. Car owners therefore expect a similar outcome with batteries.

Regardless of the battery state, in 2009 McKinsey was already certain of the overtake of electrified vehicles with a direct impact on the automotive, battery and utilities economies [13]. In the same year, Warren Buffet started investing in the Chinese company "BYD", specializing in battery and electric car production [14]. Whether it was the very real danger of the upcoming global warming effects, or the penetration of renewable energy sources into the grid that started the trend of electric vehicles, it does not matter. The trend started and was encouraged by celebrities and investors.

The true game changer however, is Elon Musk. The CEO of the car manufacturing company Tesla, Inc., named after the famous Serbian inventor of the alternating current Nikola Tesla. After establishing the company in October 2008, Musk focused on the design of the vehicle. The cars are to be 100% electric, able to travel more ranges and to be charged with a simple plug. The state of the art capabilities of the new Tesla cars were not enough to catch the attention of the people. The elegant sport car seen in Figure 5, designed with a futuristic cockpit, elegant seats and amazing features grabbed everyone's attention. Furthermore, it is able to deliver a rotation speed up to 13000 rpm, which enables the car to have a very high performance without a clutch pedal and allows unskilled drivers to experience the sport car life [15].





**Figure 5:** Tesla Roadster (997 km range) [16]

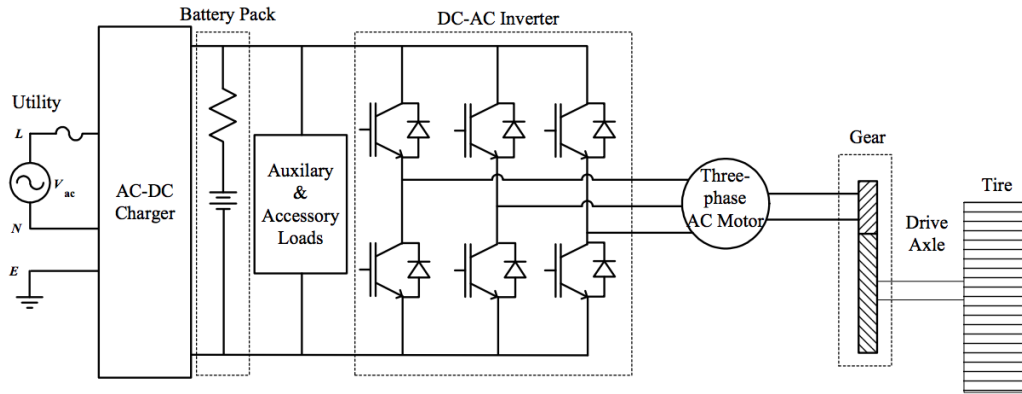
The Lithium-ion battery has proven to be the battery balancing nowadays between durability, cost and performance. Therefore, similar to Tesla, most electric car manufactures are using this technology until further technological breakthroughs [17]. There are three levels of vehicle charging, which require various time to charge and hence have different charge power. An overview of these levels are shown in Table 1 below..

Level	US Voltage	EU Voltage	Current	Power	Time to charge
1	110V	120V	15A	1.4kW	18 hours
2	220V	240V	15A	3.3kW	8 hours
2	220V	240V	30A	6.6kW	4 hours
3	480V	400V	167A	50-70kW	20-50 minutes

**Table 1:** Levels of vehicles charging [18][17]

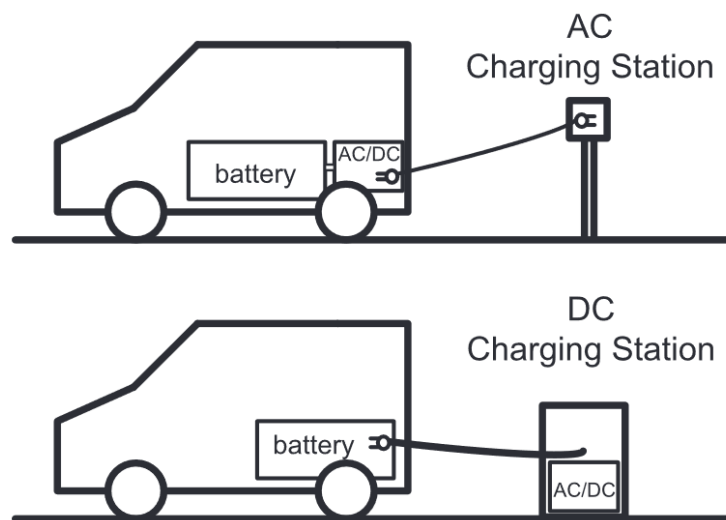
Depending on the needed utility service, the car can be charged in specific stations, requiring different plugs and different measurements. These requirements were standardized and transitioned to be able to handle the required load in a safe manner.

The electrical scheme of an EV, can be simplified with the following block diagram on Figure 6 [18]. There the AC-DC Charger can be seen connected to the the ground on the left side. This is followed by a battery pack, which then connected to its auxiliary and the accessory loads which are variable depending on the vehicle and the load. A DC-AC inverter then converts the energy to alternating current and connects it to the gear through a three phase AC motor. In the motor the electric alternating power is converted to mechanical power, which is why the gear can start rolling the tires and the car can move rolling on its wheels.



**Figure 6:** Electrical block diagram of an EV [18]

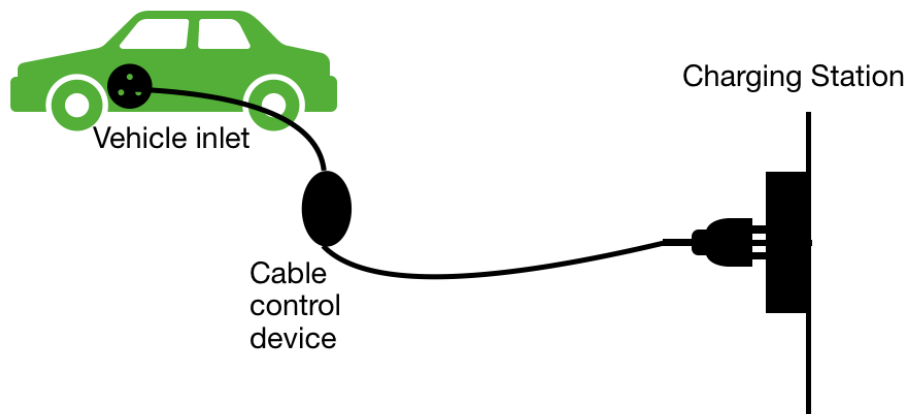
The majority of EVs are charged via a Plug. Therefore there are two trajectories that must be distinguished. The Alternating Current and the Direct Current charging, which is according to Peter Fairley is the upcoming war of currents [19]. To be able to conventionally charge the EV at residential areas or offices an AC charging station is required. The resulted AC power must be converted to DC through a small converter inside the vehicle. Charging the vehicle through an AC station requires more time than through a DC station, since the DC station has a bigger, better and more expensive AC/DC converter inside the station pole as seen in Figure 7 [20].



**Figure 7:** Scheme of an AC and a DC charging station [20]

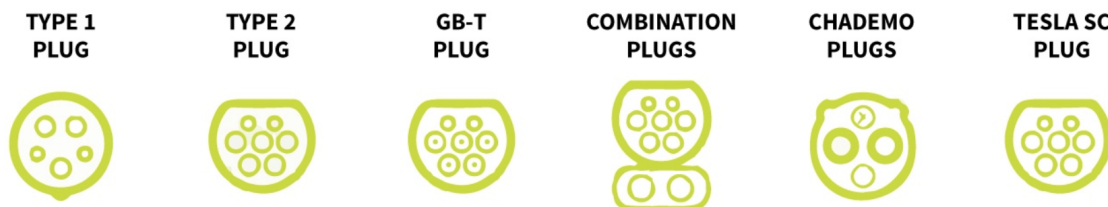


Adding a bigger AC/DC converter inside the vehicle would make the charge time shorter, however it would be much more expensive and use up much more space thus more energy. The vehicle inlet, is plugged into the outer socket with a cable. Here the supply is extracted through the charging station regardless the type. This is standardized through IEC 62196-1[20]. The Figure 8 below shows a sketch of the introduced standardized form of EV charging showing the cable and the vehicle inlet with a cable control device.



**Figure 8:** IEC standardized 62196-1

Over the years different types of plugs have been developed by different companies and countries. These plugs can be seen on the Figure 9 below. Here the Type 1 Plug is single-phase plug mostly used in Asia and by Asian car manufacturers. Type 2 is the standard plug in Europe and is a triple-phase type. The upgraded version of type 2 is the GB-T plug that has additional male connectors. Another type of upgrade of type 2 can be seen under the Combination plugs and includes additional power contacts enabling faster charging. The Japanese developed the Chademo plugs, which are considered to be a quick charging cable that works very well. Additionally, Tesla developed their own plug, called Tesla Sc which enables their Tesla vehicles to be charged from the Tesla stations in the most efficient and safe matter for the cars.



**Figure 9:** Plug Types [21]

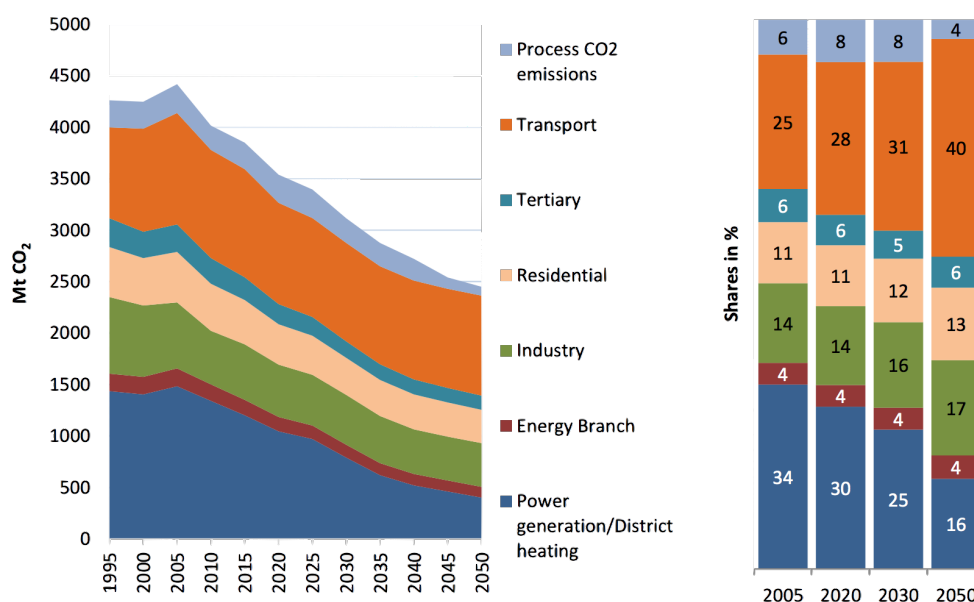
However the future expects no Plug in cables for EVs, the trend has already started

with the first electrical highway built in Germany for electric trucks in 2017 and officially opened in 2019 as seen in Figure 10 below.



**Figure 10:** The first E-Highway in Germany [22]

This was built by Siemens after the European Commission proved that transport will be the biggest challenge for decarbonization in Europe [23] as can be seen below. The Transport CO<sub>2</sub> impact is highlighted in orange and presented in mega tons every 5 years.



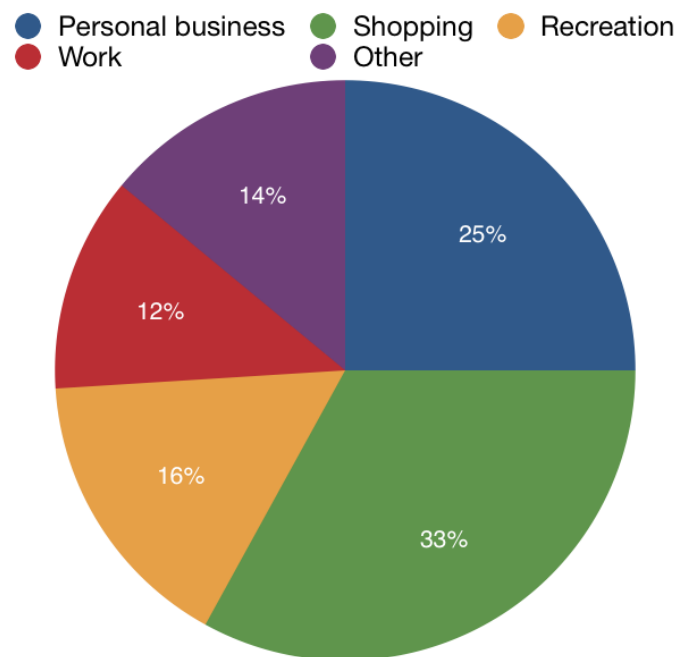
**Figure 11:** CO<sub>2</sub> generation [23]

This proves the necessity of decarbonizing the streets and introducing Smart Mobility.

## 2.2 State of the Art Car-sharing

A Car-sharing company provides its members with a service to access their fleet of vehicles. This allows users to pay the fee for the ride and they are charged on an hourly or distance basis [24]. Initially the fleet of vehicles was thought to be privately owned and publicly shared also known as a Peer-to-Peer Car sharing [25]. Two different use cases result from this plan. The first being an agreement between the car owner and the car sharing company, allowing their vehicle to be rented out. The second being the agreement between the fleet user, who has the freedom to use any car at any time. However, this thesis will focus on the company owned vehicles offering their fleet to users as a service.

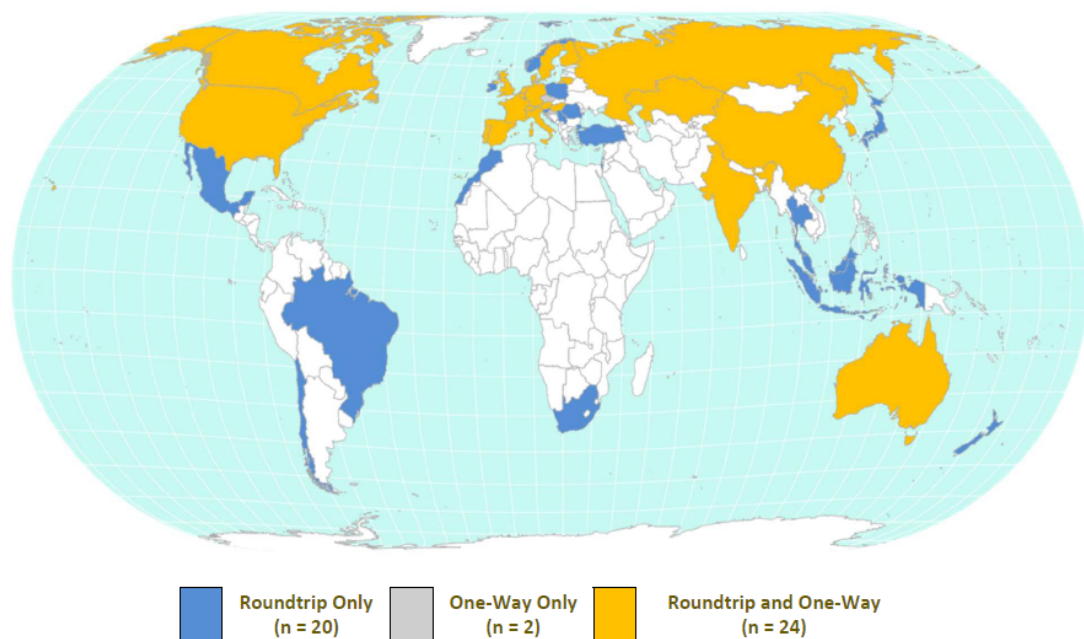
The first researches done in 2004 showed that Car-sharing users did not use the fleet on a daily basis. Instead they would use it judiciously, usually when users have heavy things to carry, or public transport is not very ideal. Figure 12 below shows that a quarter of the rides are used for personal business, whereas shopping purposed driving is roughly a third of the trips. The rest of the trips vary between recreation, work trips, commuting and other. The statics showed that on average only two trips were made per month [24].



**Figure 12:** Uses of Car-sharing

These speculations have changed a lot today and a significant exponential growth can be seen. This is a result to having introduced non station based shared cars, which only require on average four rides a day to break even.

Up until 2009, Europe had 3850,000 Car-sharing customers [26] By the end of 2016, however four million customers were active in Europe. Resulting in over 15 million users worldwide and 157,000 shared cars. The largest player being the Asian market, where the vehicles are being mainly used for round trips. Europe is the world's second biggest market for Car-sharing. The four million members use the vehicles for both round trips and one-way trips. The following Figure 13 shows countries with active Car-sharing usage. Whereas the blue highlighted countries mostly use the service for a round trip, the yellow highlighted for both trips, and the grey shows only one-way users. [27]



**Figure 13:** Global Car-sharing map [27]

It is clear from the map above, that depending on the resident's mentality with regards to public transportation, different behavior can be expected. In South America for instance, users are expected to use the vehicle as a door to door service. Bringing them both to and from the target location in a luxurious private way. The fact that almost the entire Middle East and North Africa region is a Car-sharing free zone is not surprising, as car ownership is an indicator for social status. There, the social standards define the people's way of living. If someone is rich, they are expected to have their own car, and if someone is poor, they use public transportation. This dominant social class structure, prevents different segments of the population from sharing the same transportation methods. For that reason Car-sharing will not be expected anytime soon for this area.

A brief overview of reasons why Car-sharing is successful in different countries/areas in Europe can be seen on Figure 14.

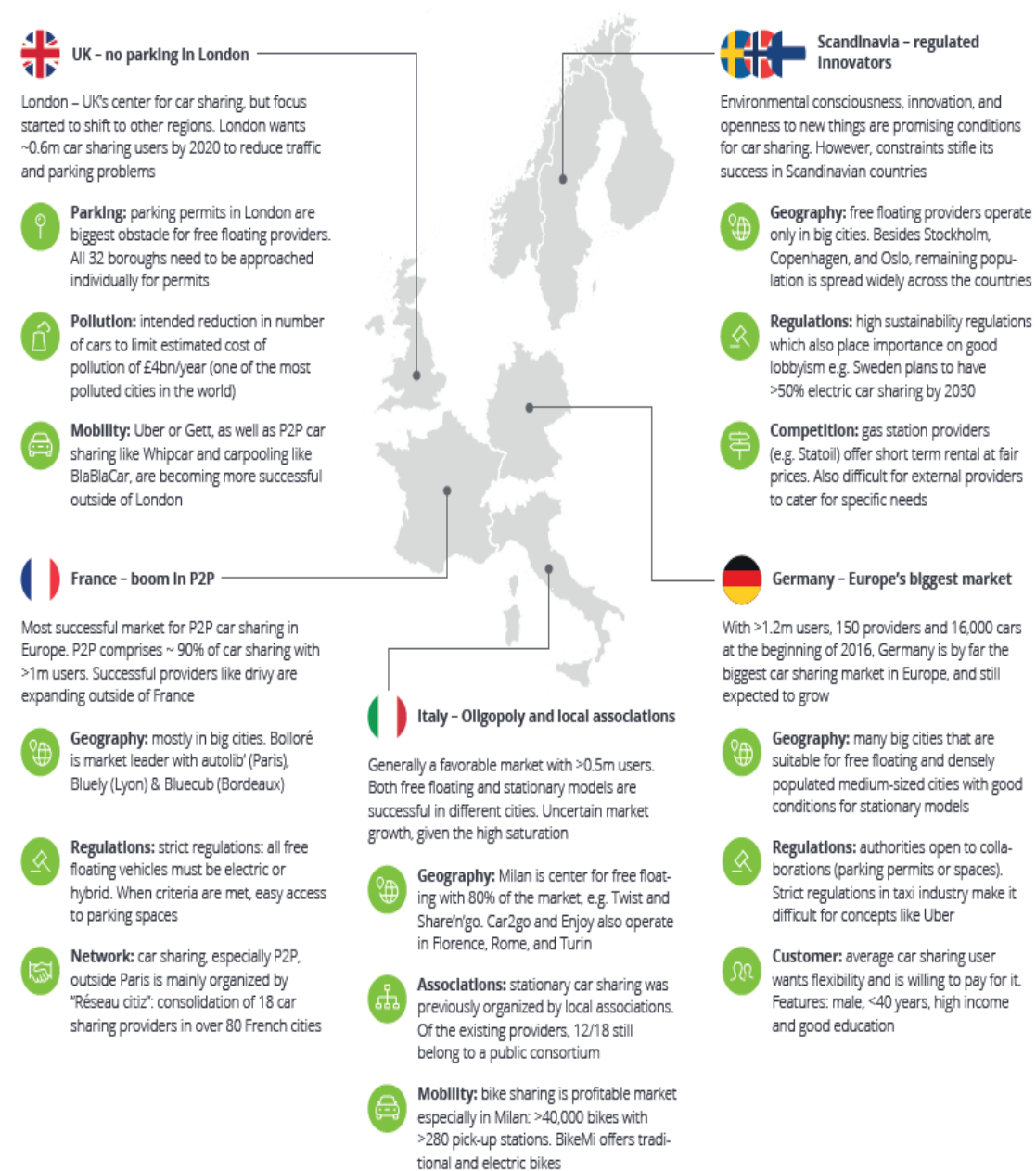
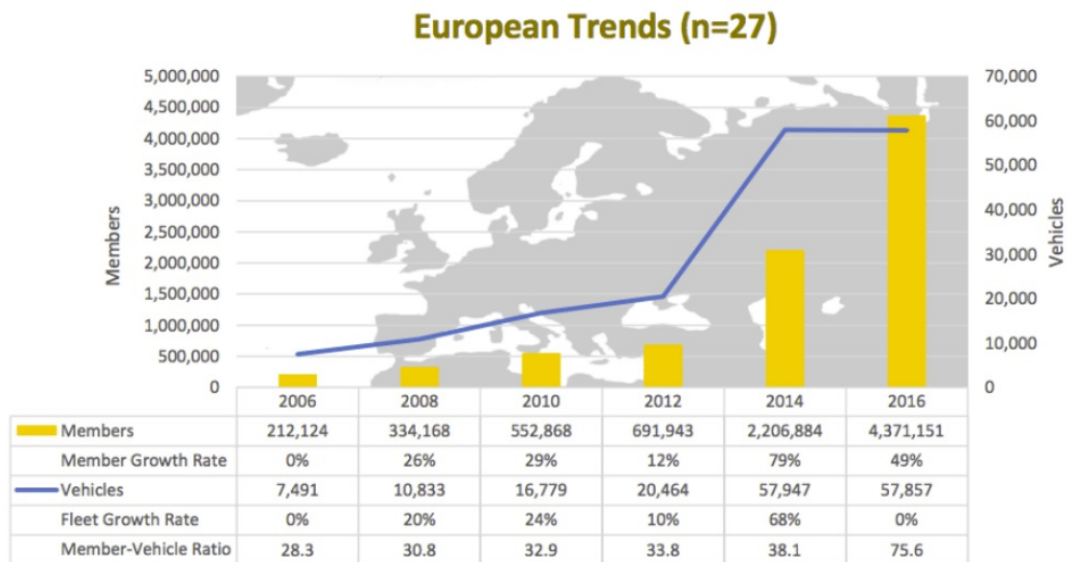


Figure 14: Car-sharing success landscape [28]

The European Car-sharing mentality is expected to grow more after the massive growth that can be seen on Figure 15 between 2006 and 2016.



**Figure 15:** European Car-sharing trends [29]

In Germany specifically, there are two different business models for Car-sharing companies. One that is Station-based, where there are fixed stations throughout the city, where users can pick up and drop the car. Or the Free-floating model, where customers are allowed to pick up and drop off the car freely within a specified zone. The following Table 2 provides descriptive statistics of the total number of available vehicles, Car-sharing members and location availability in Germany up until 2017.

	Station-based	Free-floating
Vehicles	9,400	7,800
Members	455,000	1,260,000
Locations	600	12

**Table 2:** Urban quarters [30]

The largest providers for Station-based Car-sharing in Germany are: Stadtmobil, Cam-bio, teilAuto, Flinkster by DB, and book-n-drive. Only Stadtmobil and book-n-drive are considered in the top five Free-floating providers. These are preceded by car2go, DriveNow and Multicity [30]. These top three companies are subsidiary companies of worldwide famous car manufactures. For example Daimler, the manufacturer of Mercedes Benz cars and smart cars introduced their own car fleet "car2go", while BMW is offering "DriveNow" and citroëen its "Multicity". Similarly DriveNow by BMW and



Multicity by citroën. These manufacturers have successfully understood the urgency of keeping up with transportation developments and using them in their favor. In 2019 car2go and DriveNow announced that they will be merging and creating SHARE NOW together. This fleet will be the largest free-floating Car-sharing in Germany, eliminating competition in this sector in 30 metropolis with 20,000 vehicles [31]. Considering the fact that 45% of Station-based users also use Free-floating services [30], there is a very high chance of a complete elimination even of Station-based providers. That is if SHARE NOW is able to beat the low prices offered for long rentals by Station-based companies. A brief overview of prices from car2go, DriveNow, Flinkster and Stadtmobil can be seen in table 3. In the table Free-floating providers can be distinguished by their blue highlighted background, whereas the Station-based providers are highlighted in light orange.

Company	Car Models	Registration fee	Price/min	Price/ 24 hours
car2go	Smart fortwo	9 €	0,19 € - 0,31 €	79 € (0,05 € / min)
	Mercedes-Benz A-Klasse		0,28 € - 0,38 €	99 € (0,07 € / min)
	Mercedes-Benz B-Klasse		0,31 € - 0,39 €	109 € (0,08 € / min)
	Mercedes-Benz CLA, GLA		0,31 € - 0,39 €	109 € (0,08 € / min)
DriveNow	BMW i3	29 €	33-36 Ct/min	109 € / 159 - 199 €
	BMW i3 with Range Extender			
	BMW X1			
	BMW X2			
	BMW 1			
	BMW 2 Active Tourer			
	BMW convertible			
	MINI convertible			
	MINI 3-doors			
	MINI 5-doors			
	MINI Clubman			
	MINI Countryman			
Flinkster	Mini (Smart, Toyota Aygo, Citroen C1 ...)	Without BahnCard: 29 € With BahnCard: free	18-22 Ct/min	39 € / 29 €
	Small (VW Polo, Opel Corsa, Ford Fiesta ...)			50 € / 29 €
	Compact (Opel Astra, VW Golf, Seat Leon ...)			60 € / 39 €
	Middleclass (Ford Mondeo, VW Passat C )			70 € / 49 €
	Transporter (Ford Transit, Opel Movano)			80 € / 59 €
	Fancy (Volvo XC 60, BMW 5er, Audi A6 )			90 € / 69 €
	Luxury (Volvo XC 90 )			110 € / 89 €
Stadtmobil	Mini(Toyota Aygo)	39 €	0,50 € - 1,50 €	0,16 €
	Small(Ford Fiesta, Renault Zoe Elektro)		0,50 € - 1,80 €	0,19 €
	Medium(Ford Focus, Renault Kangoo)		0,50 € - 2,30 €	0,21 €

**Table 3:** Car-sharing overview in Germany 2019 [32][33][34][35]

New start-ups are trying to penetrate the market by charging per kilometer and offering special deals. Whether they will be able to survive against the German car giants still remains questionable.

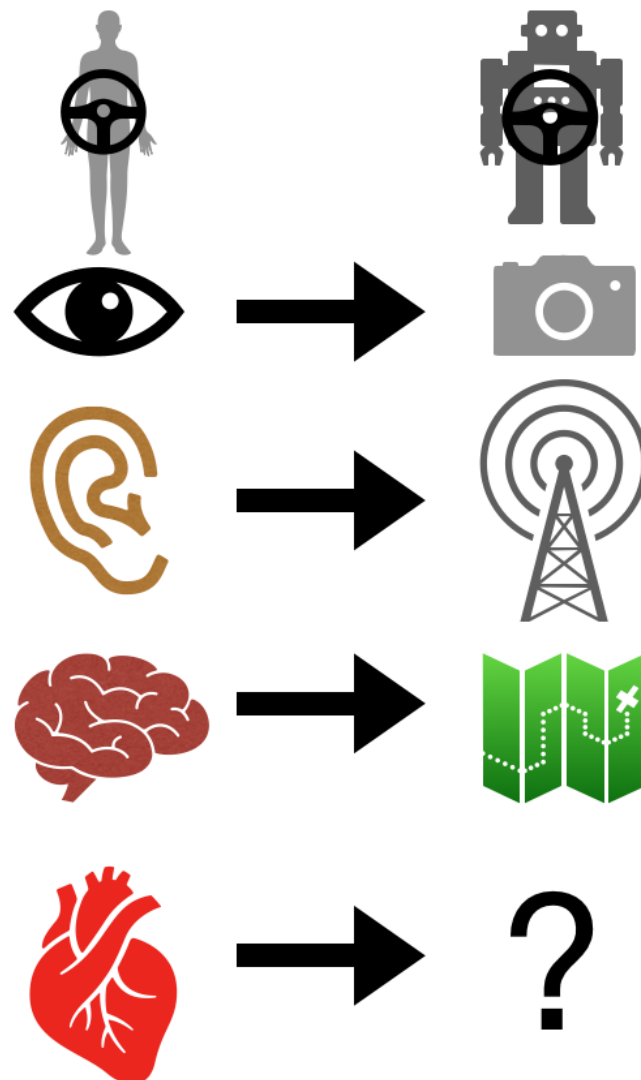
The potential of Car-sharing is enormous, and current statistics underline its increasing growth, ultimately potentially substituting public transport rail systems. The 24th of November 2015, the public transportation system in Vancouver Canada was temporarily out of service. During this time period, the use of Car-sharing services multiplied, triggering a debate on whether Car-sharing could substitute public transportation was starting to arise showing the first positive evidence [36]. Even in London a study showed that 37% of the users are impacted by Car-sharing, resulting in them either not buying a car, or selling their existing car [37]. The question therefore rises, as to whether the governments should allow their transportation vehicles to be privately owned by different companies. Will a monopoly arise as a result to economies of scale? Moreover, will everything be subject to regulations or are the companies going to have limitations soon?

In all cases the future of Germany's multinational car manufacturing companies and with it German's GDP is heavily at risk. Needing both the companies and the government to cleverly adapt to the future of transportation systems. These issues will be discussed in the following sub chapter [2.3](#).



### 2.3 State of the Art autonomous EVs

Autonomous electric vehicles are eVs that can operate with limited/without human intervention. They work with sensors and cameras, which allow them to detect objects and navigate to a certain direction [38]. These vehicles are also known as UAV, Unmanned Aerial Vehicles and have been showing a lot of potential in the past couple of years [39]. There are different levels of autonomous vehicles, the higher the level, the less interference is required by the human. Starting level 4, the vehicles are expected to be able to fully move around on their own [40]. How they work and how they substitute human intervention is shown in Figure 16 below.



**Figure 16:** Human vs. Autonomous driving

In the figure above, the senses the human uses while driving are presented on the left side, while the substituted features by an autonomous vehicle which can be viewed as a robot, can be seen on the right. A human's eye, will be substituted with a camera and sensors, which allow the vehicle to "see". The ear is replaced by the "vehicle to everything (V2X) communication", which allows the vehicle to be at constant communication with the street, other vehicles on the street, the grid and much more. This vehicles to everything communication will be enabled by the upcoming 5G network, aiming to accelerate the human services and communication.

The brain, which understands and remembers roads, will be replaced by the integrated GPS, which will be updated in real time with the help of the V2X communication together with artificial intelligence, to be the smartest, most accurate navigation system. While these smart devices, will help the vehicles to reduce traffic and traffic accidents, there is still a social dilemma that the vehicles might encounter. The very same dilemma a human might encounter, where they would act with their heart, rather than rationally. This occurs when one has to choose between two evils and there is no way out [41]. In other words, when it is a choice between hitting different people or objects. Do you hit the little kid playing on the street or the old couple sitting on the bench? Do you hit a million Euro car or an old historical building?

This is solved by teaching the vehicle morals and allowing it to quickly calculate the best outcome. Yet, morals are different all around the world. Where a European driver would rather hit the old couple, justifying that the child still has its entire life to live. An Arabic driver might do the opposite, justifying that there are more people dependent on the older couple, who would be destroyed if anything were to happen to them.

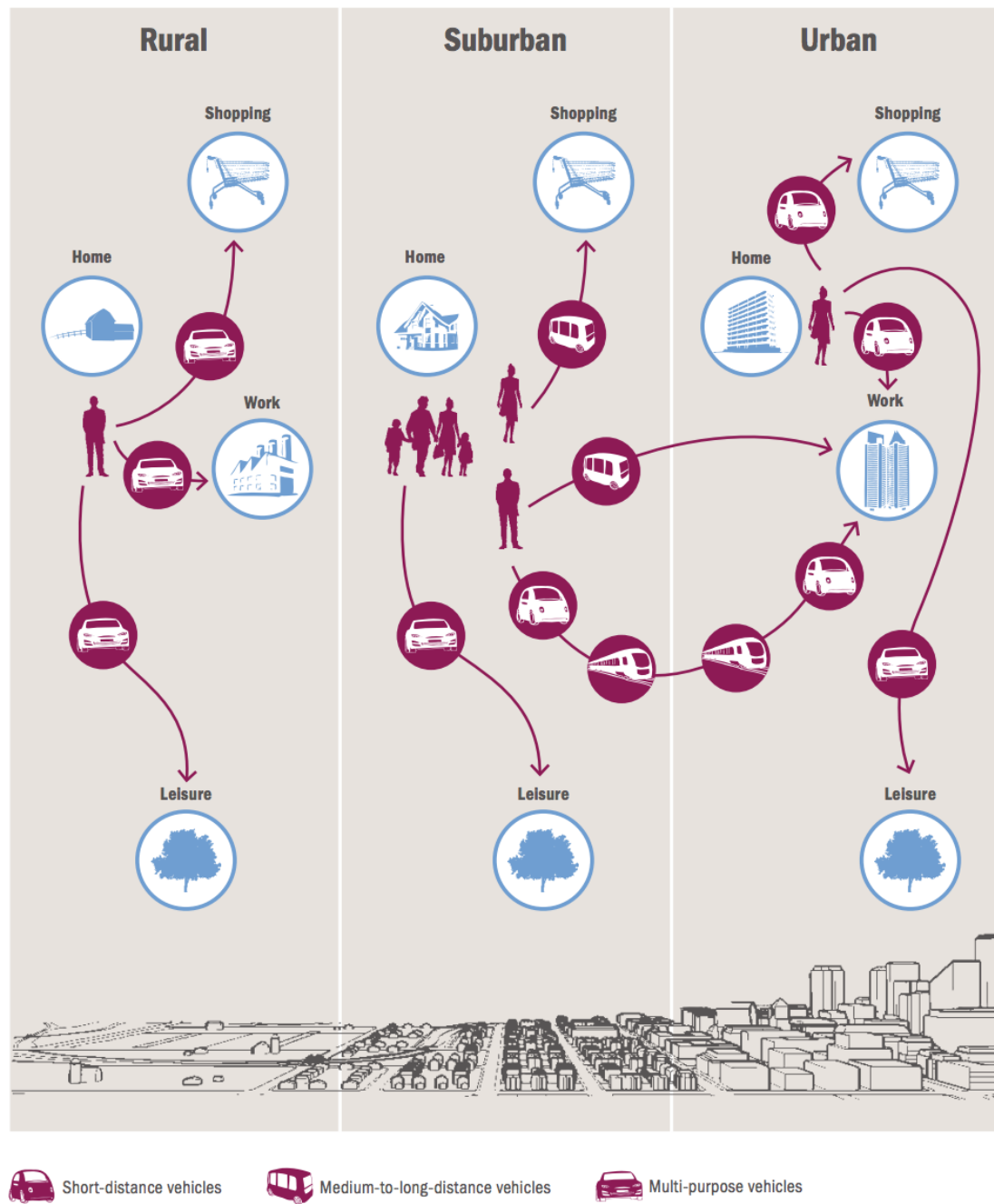
A machine could be unable to compare between morals and choose what it thinks is right, as morals are the result of more complex train of thought that stem from culture, religion and tradition, all of which can be taught to a machine but cannot be felt. Therefore whether a heart could ever be replaced by machine learning is a question that cannot be answered. The question mark on Figure 16 next to the heart illustrates this challenge.

There are five levels of autonomous vehicles, excluding the basic level 0. The higher the level the less human interference is required. This is important to show, since this thesis will be dealing with level 4 autonomous vehicles. Table 4 below, gives a brief overview of abilities of each level based on SAE J3016 [42].

Levels	Human interference	Automated conditions	Automated features
Level 1	At all times	Warnings, momentary assistance, steering OR brake & acceleration	lane centering OR cruise control
Level 2	At all times	Warnings, momentary assistance, steering AND brake & acceleration	lane centering and cruise control
Level 3	When requested	Level 2 & complete driving under limited conditions	traffic jam driving
Level 4	Never needed	Level 2 & complete driving under limited conditions	local driving
Level 5	Never needed	Level 2 & complete driving under all conditions	local and global driving

**Table 4:** Lines information

With the rise of artificial intelligence and even more intelligent power electronics components, these vehicles are able to drive almost error-less. UAVs are expected to be fully electric, thus reducing CO2 emissions on the roads and supporting the electrical grid with their built-in battery when needed. On Figure 17 below three different sizes of the vehicles, a small, medium and large sized vehicles are illustrated in different locations for different purposes.



**Figure 17:** Different sizes and purposes of vehicles in different locations [43]

This thesis will be considering the IAV developed vehicles, HEAT (Hamburg Electric Autonomous Transportation). These vehicles are designed as mini buses, which are able to drive, park and navigate without any direct human intervention. They are about 5 meters long and can fit up to 16 passengers. HEAT vehicles are expected to drive inside cities only, which is why their maximum velocity is set at 50km/h. In 2019 the vehicles are being tested in a fixed zone, with a little human intervention, and by 2021 the vehicles are expected to be driving completely autonomous (level 3 or higher) on the streets of Hamburg [44].



**Figure 18:** Hamburg Electric Autonomous Transportation [44]

Autonomous vehicles will either reduce traffic strongly or create more traffic. This will depend on the system adopted by the political situation regionally. Meaning that, if residents were allowed to let their autonomous car drive freely, they could create chaos by constantly sending their cars on route somewhere. However, if this is regulated through a sharing community or other models, a huge potential can be foreseen.

France has already introduced multiple autonomous shuttle buses in Lyon and La Défense starting 2016. In the Swiss Sion two autonomous shuttles have been driving passengers around the city since 2016. This was followed by Las Vegas, who added two buses in the Freemont quarter in 2017. Japan followed by introducing three vehicles in Fukushima, allowing an emission free transport. [45]

## 3 Smart Cities

### 3.1 Smart Cities goals

Initially the dream started as "A better future for the next generation". Today we are wishing for a habitable future for the next generations. In 2019 the world has already reached almost 410 ppm CO<sub>2</sub>. That is a huge problem since, according to research if by 2100 the world wants to stay below a 2°C temperature increase, it should have a maximum of 450 ppm CO<sub>2</sub>. The European Union already signed up for a 2020 deal, agreeing to lower their greenhouse gases by 20%, increase their energy efficiency by 20% and to have 20% of their electricity coming from renewable energy sources. These are spread between different countries depending on the marginal abatement cost for a ton of CO<sub>2</sub> reduction. A perfect Emission Trading System is set in place, allowing members of the European Union to buy and sell the CO<sub>2</sub> certificates they own. The certificates system is a way to maintain and control the CO<sub>2</sub> production, where each player has to buy certificates to emit CO<sub>2</sub>. The higher the amount, the more expensive the certificate, which is still less expensive than the fine companies would pay if they did not have a certificate.[46]

Smart Cities ultimate goal, is to reduce greenhouse gases and not exceed the 450ppm CO<sub>2</sub> limit. These are the most realistic, achievable goals smart cities have today.

However, to make this happen, multiple scenarios will be shown underlying the expected action from the governments, private entities and residents.

### 3.2 Possible Scenarios

The definition of a scenario is at utmost importance to understand the following sub-chapters. Scenarios are merely thought experiments that help understand the possible consequences of certain actions. They can never be seen as a forecast of the future, since they are just building a possible image. Keeping in mind that a lot of uncertainties and indeterminable events could drastically change the scenario outcome. [47] These scenarios are based on facts such as population growth, productivity growth and speculations on further world developments, looking a decade into the future.

### 3.2.1 Business as usual (Base line)

This scenario ignores any environmental policies. Assuming that everything stays at is, expecting a linear growth both in population and technological development will raise a huge environmental challenge. If the industries are not forced to modify their production and distribution to a more environmentally friendly process, it is very unlikely that they would do something about it, hence the Very low label in 5.

The Economy on the other hand, which will be presented by the world's GDP will keep rising, allowing the exponential growth of GDP to continue. The High labeled economy, shows therefore the positive impact on the economy. The technological tab is neutral, since it will be growing and developing, but not necessarily in the correct direction. It might do the world some good but it might also create a lot of damage.

This is however very theoretical, since the negative impact on the environment will be so big, a world might not even exist anymore.

Economy	Environment	Technology
High	Very Low	Neutral

**Table 5:** BAU scenario

### 3.2.2 Policies towards sustainability

In the case that hard, well defined targets are forced to reach an emission free world as quickly as possible. Two different scenarios will emerge depending on the kind of policy introduced.

If the policy is very strict for example like stopping fossil fuels completely, the world GDP will have a steep fall. Since the world economy still heavily depends on fossil fuels for production. Thus the technological development will stop completely resulting in a negative outcome. The environment however will be positively higher. This a very unrealistic scenario, since everyone will have to completely change their way of living.

Economy	Environment	Technology
Very Low	High	Very Low

**Table 6:** Policies scenario -strict

On the other hand, if the policies are not very strict, the economy GDP will stay neutral, the environment will be a bit better but not so much and the technological advancements will be neutral tending to a positive impact.

### 3.2.3 Policies and Demand Side Management

Understanding the consequences and the price the world would have to withstand in order to help save the world, an alternative solution was put into place. Integrated Source planing was put into action to encourage citizens to not only buy more energy efficient products, but to also become more aware of their consumption. Under this idea Demand Side Management was introduced. The idea was not only to manage the energy generation but also the demand and use by residents, without forcing it. By introducing Smart Meters and other Smart gadgets, citizens could have a more concentrated overview of their consumption. In addition, with the rise of artificial intelligence, these products were able to learn from their user's behaviour and act accordingly. They offer their users a more comfortable way of living, while helping reduce their unnecessary consumption. This went a step further, allowing the Distribution System Operators to offer their clients different rates of electricity depending on their flexibility of consumption. Meaning that, a user who would like to run their washing machine at a certain peak hour would be asked to wait a couple of hours and receive a reward in some kind. The user would get the choice to then be flexible about the wash or not. The more flexible they are, the less expensive the wash is for them and the more the DSOs can support the fluctuations of Renewable Energy generation. By doing so, a more fluid generation can occur and the electric load diagram's peak will be shaved.

Introducing this system together with EVs enables Demand Side Management to be even more effective. By charging the eVs, when the generation is high and the demand is low, and discharge them when the demand is high. The eVs offer the decentralized residential areas more flexibility and hence more support to Renewable sources.

EVs have the huge benefit of not being used, when the demand is high. Meaning that, if the demand is high, a lot of residents are at their work place or at home consuming electricity. If some of the EVs can be discharged then, the challenge of introducing renewable to the grid will not be so hard. The environment will get much better, while technological advances and research and development will help the world GDP to be higher. Resulting in the 7 to be completely positive.

Economy	Environment	Technology
High	High	High

**Table 7:** Policies and Demand Side Management scenario



## 4 The City of Berlin

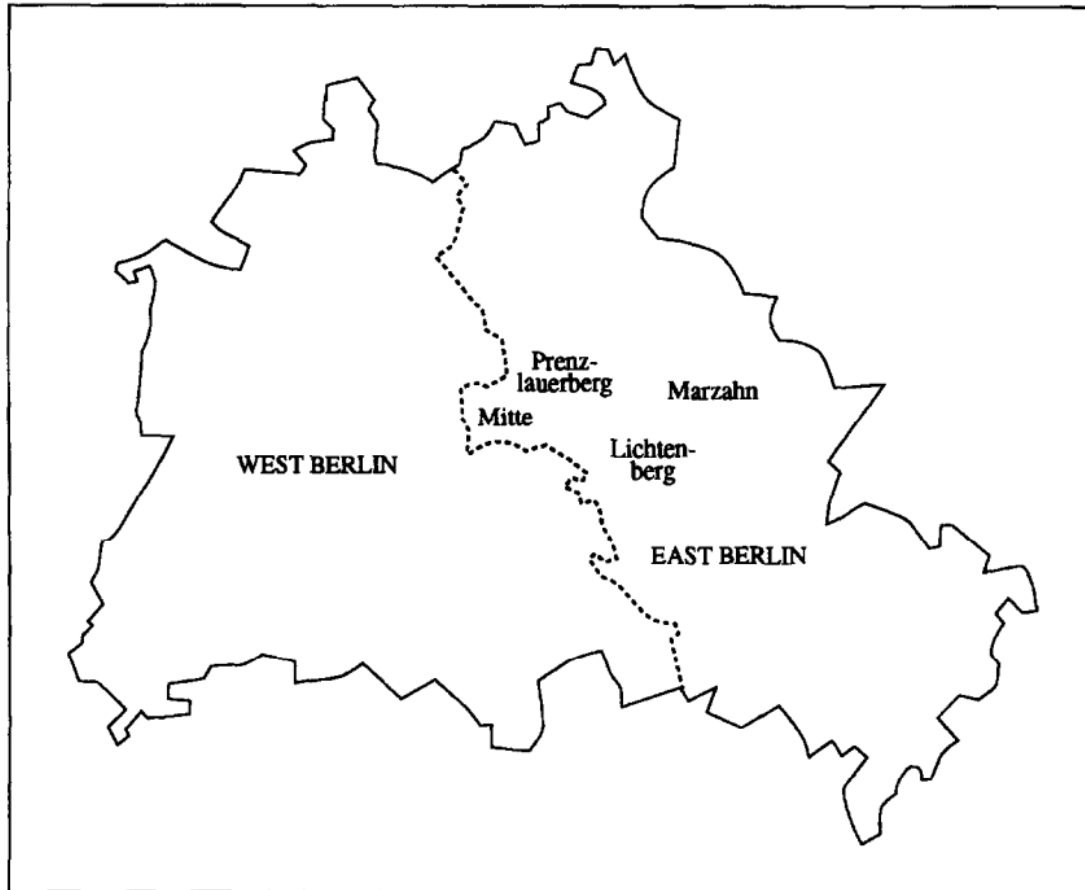
### 4.1 General Introduction

Berlin has been the capital of Germany since the 1990 German reunification after World War 2, prior to that it was the capital of the German Democratic Republic and the German Empire before that. By the 1920s Berlin had a population of four million people and the city infrastructure was designed accordingly. With the electrification of the city rail, a new transportation system was designed taking the four million people into consideration [48]. Today Berlin is home to millions of people of different backgrounds and interests[49]. The city offers a wide range of big and small companies, universities teaching a wide range of subjects, and a developing universal entrepreneurial scene[50]. It is attractive for the variety of attractions it offers, such as festivals and arts centers. With these offers more and more people move to Berlin; these vary from Europeans to expatriates looking for a new start [49]. However, to maintain the image and the high quality of life [51], the infrastructure has to be well-kept. This is an arising challenge mainly because of the lack of available housing and the complexity of a proper transportation system. In Figure 20 below, the 12 city boroughs are shown. These have to offer more housing while being well-connected to one another via public transportation.



Figure 19: Map of Berlin [49]

Contrary to other metropolises, Berlin has a very big city center as a result of its unique history. The different political sides, the democratic west and the communistic east, hindered any potential for further growth on either side. With a connected Germany, this problem would no longer be there and Berlin would have more potential to grow into a community of neighbouring suburbs.



**Figure 20:** Map of Berlin 1946 [52]

In this chapter, the arising transportation and housing challenges, as well as the state of the art of transportation in Berlin are introduced. These will then be followed by proposed solutions and a more detailed explanation on one of the mentioned solutions.

## 4.2 Transportation in Berlin today

Berlin's public transportation system is run by two companies. The BVG (Berliner Verkehrsbetriebe) is responsible for designing and running the U-Bahn, tram, and buses, and the DB (Deutsche Bahn) is responsible for the S-Bahn and regional trains. The system is simple to understand yet complex to build and design. It is designed to ensure passengers' safety, well connection, and a short waiting time between trains.

With the growing interest in Berlin from tourists and new residents, the transportation system has to upgrade. Each year, increased safety measures such as cameras and safety guards, as well as solutions to improve the vehicles' punctuality are introduced. This resulted in almost 1.064 million passengers using the BVG [53].

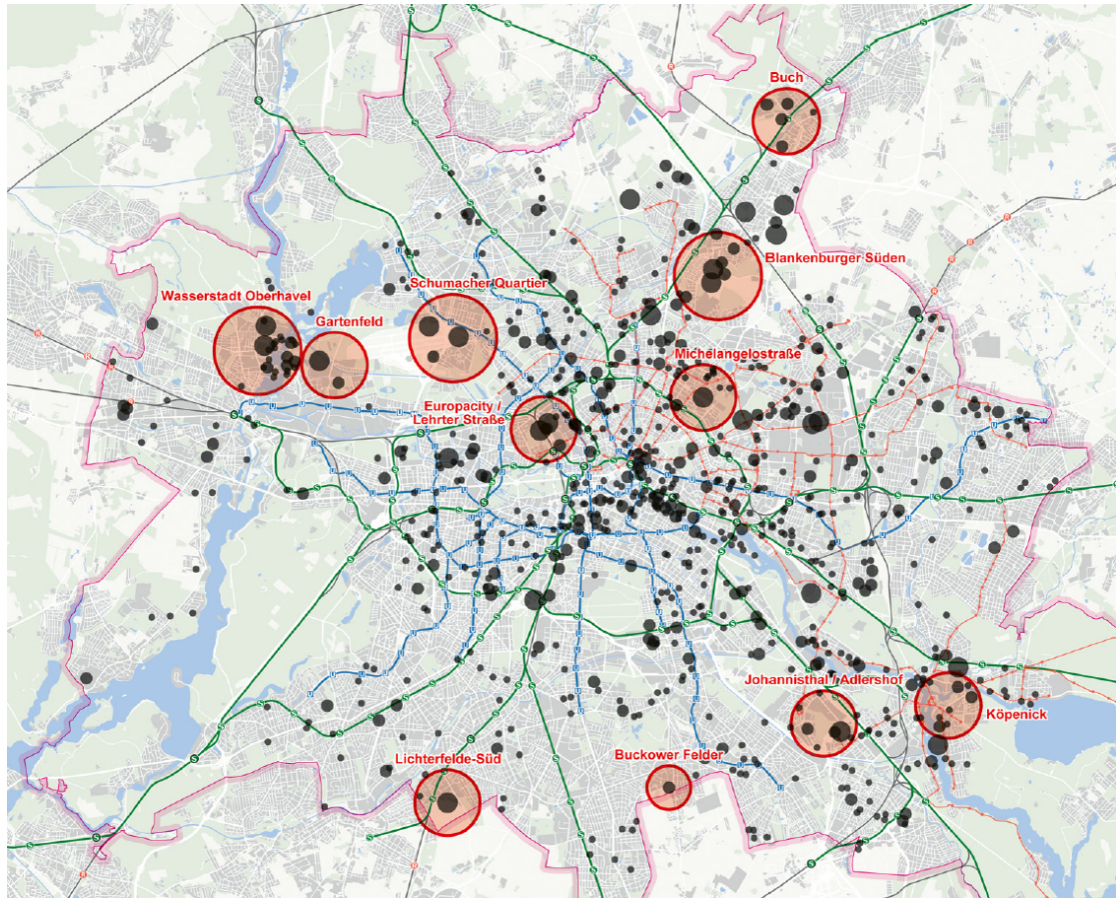
The DB runs sixteen S-Bahn lines all over Berlin; these are extended to Brandenburg through faster, regional trains. These are designed to be connected to the U-Bahn lines and buses, and are focused on the inner Berlin ring [54]. The BVG, on the other hand, runs the tram and bus lines and 26 U-Bahn lines.[53] These lines intersect in various popular spots as seen in Figure 21 below.

They are all connected through a platform and an application that is able to calculate the best route for a passenger. This app can detect any delays or failures and adapt to a new route accordingly, as well as sell tickets electronically. Every year, the BVG and DB try to improvements to ensure customer satisfaction and safety. However, they have much more inquiries than the solutions they can offer, and still end up not breaking even the cost of work performed. The demand of the German railway system is not only attractive to its citizens, but also offers tourists an easy way to travel within the country. This is in contrast to other countries, where one has to rent a carâ a huge plus for tourists but an extra challenge for the responsible transportation entity. The current railway system can not adapt to the tourism high/low seasons, nor to the change of seasons in which other transportation methods, such as bikes, impact the demand of public transportation.

### 4.3 Berlin expanding residential areas

This is why Berlin has decided to expand its neighbourhoods and include 11 new urban quarters, as can be seen in the red circles on Figure 22.





**Figure 22:** New residential areas in Berlin [58]

This map represents the city of Berlin, with the green lines showing the S-Bahn flow, and the blue lines displaying the U-Bahn route. The 11 red circles, which represent the new urban quarters, demonstrate the size of the expected residential units.

These new quarters are expected to be designed in a simple yet smart way to house as many people as possible without lowering their quality of life. Social gathering places, including restaurants, cafés and parks are taken into consideration. Adding to that, a leisure-/work infrastructure is included in the design to ensure a proper work-/life balance. This is essential to maintain a neighbourhood with harmony and stability. Here, the German traditions and habits are considered and rules are set accordingly [58].

A proper and well-designed transportation system is an important factor to maintain the ideology of the new quarters. There are only four quarters, in which neither the S-Bahn line, nor the U-Bahn line pass through: Buckower Felder, Köpenick, Gartenfeld and Wasserstadt. These are represented below with the potential residential units and the expected project end date in Table 8 [59].

Urban quarter name	Potential residential units	Expected end date
Buckower Felder	800-900	unknown
Köpenick	1000-2000	unknown
Gartenfeld	3000-4000	2025
Wasserstadt Oberhavel	4.500-5.500	2023-2025

**Table 8:** Urban quarters [59]

## 5 Case study

### 5.1 The Location

In order to design and test an actual case study, multiple external factors have to be taken into account after choosing the location to be studied. Gartenfeld was chosen for this thesis. This decision has been made based on the following reasons;

- The large size of the population
- the neighboring quarter of Wasserstadt Oberhavel
- the vision of its politicians of turning Gartenfeld to an environmentally friendly city

This mindset makes the potential of this thesis much more promising and the integration much more realistic. Furthermore Table 8 shows that Gartenfeld's expected residential units number is 3000-4000, which means 7400 residents, making it ideal to prove the concept to be successful.

Gartenfeld used to be a Siemens cable manufacturing hall with no residential units. It is located between Spandau and the Airport Tegel area and is therefore a well connected area already. The fact that it is an island makes it a very attractive location for young families who want to enjoy the city as well as the quite natural life. It used to have a close by S-Bahn station that was shut down during the second world war. Adding to that two relatively close U-Bahn stations as well as a Bus that drives on the Gartenfelder street can be found. These can be seen highlighted on Figure 23 below. The S-Bahn is marked with a red S, the U-Bahn stations with a yellow U and the Bus stations with a blue B.

Assuming that the S-Bahn station is reactivated after 8-10 years, it would require citizens living on the island to travel a long distance before reaching the station. The existing U-Bahn line is about 2km away from the center of the island and would make citizens not well connected to jobs and the city of Berlin.



For this case study Gartenfeld will be a car free zone and would only allow autonomous vehicles, bikes and emergency vehicles such as ambulances, police cars and the fire department to drive through the city. Two exit and two entry points to the island and existing roads that lead to the public transportation system are designed as can be seen in Figure 23.



**Figure 23:** Gartenfeld on Google maps

## 5.2 Technical Analysis

The technical analysis of the potential of autonomous vehicles for the quarter Gartenfeld will be done with MATSim, a multi agent simulation tool designed specifically for transportation simulation. This tool enables the vehicles to virtually drive through the quarter during different iterations in 24h, ultimately calculating the perfect route to avoid traffic congestion. The tool takes multiple factors into consideration, such as the network, the populations and the events taking place. These will be clarified in the subsections to follow, showing the code while analyzing the lines and explaining the method. The technical analysis should explain the reasoning behind choosing the route, the amount of cars needed for the economical analysis as well as a virtual presentation of the vehicles flow.

### 5.2.1 The Coordinates Network

The network is the base and the foundation of the system. It consists of the designed streets with all needed points and information. It is necessary to introduce the start and stop nodes of a street, the length of it, the width of it and the maximum allowed speed. Other features such as the allowed use of transport (car, bicycle, etc.) can also be included in the streets. Figure 24 shows the architectural design of the new Gartenfeld, designed for residential, leisure, business and office zones.



**Figure 24:** Gartenfeld's architectural plan [60]



The initial design showed on Figure 24 above, helps understand the quarter better. It is worth mentioning that it is not intended to show the final design of the quarter, but a rough picture of the developer's idea. Based on this picture three lines of transportation are developed. The orange line connected to the southern part of the quarter and is connected to the U-Bahn line. The pink line, which connects the quarter from west to east to the S-Bahn, U-Bahn and Bus line. Finally the yellow line, which is in charge of driving all around the residential zone only leaving to connect to quarter to the S-Bahn line. These lines can be seen on Figure 25 below.



**Figure 25:** 3 Different routes for the vehicles



This results in the following complete flow of the quarter.



**Figure 26:** Vehicles lines in Gartenfeld

To add this course on MATSim, the first step is to download the existing map from Java Open Source Map (JOSM). JOSM is an open street map, which allows free downloads of existing locations in Java format [61]. After doing so, the package MATSim is downloaded and installed, allowing JOSM to convert the map into MATSim data.

This data then replaces all existing nodes and streets withing Gartenfeld. This process is very long and has to be done in a very precise matter, considering all nodes connections and lines. After doing so, all nodes from Gartenfeld must be added together with their parameters and connections to existing nodes.



In order for this step to happen, all needed nodes are defined as can be seen in the figure below. Here the large pink numbers on the pink line show all branches the vehicle will be driving on. This is necessary for MATSim to understand its network properly.



**Figure 27:** Nodes and Lines

These points are then sought out on google maps, defining their correct longitude and latitude coordinates on the real map. The table below represents the line color, the node's personally defined ID number and link number, as well as the distance of the line in meters. The latitude and longitude coordinates and the equivalent x and y coordinates for MATSim. These will be explained more in 5.2.1.1

Color	ID	Link ID	distance to next (m)	lat	long	x	y
Pink	260405738	7465_0_ps	167.3				
Pink	74651	7465_0_p	269.1	52.554596	13.2381576	1473665	6901031.4
Pink	74652	7465_1_p	170.3	52.553099	13.24128	1474012.6	6900757.3
Pink	74653	7465_2_p	540.2	52.551913	13.2396841	1473834.9	6900540.2
Pink	74654	7465_3_p	84.1	52.548943	13.2460005	1474538	6899996.5
Pink	74655	7465_4_p	104.3	52.549542	13.246762	1474622.8	6900106.1
Pink	74656	7465_5_pg	18.30	52.548992	13.2480105	1474761.8	6900005.5
Pink	29706776						
Orange	33483671	672643_0_os	24				
Orange	6726431	672643_0_o	80	52.55029	13.2362878	1473456.8	6900243.1
Orange	6726432	672643_1_o	167.5	52.550132	13.2373626	1473576.5	6900214.2
Orange	6726433	672643_2_o	322.6	52.551274	13.2389743	1473755.9	6900423.2
Orange	6726434	672643_3_o	400.8	52.549434	13.242656	1474165.7	6900086.4
Orange	6726435	672643_4_os	102.6	52.546656	13.238878	1473745.2	6899577.8
Orange	253250196						
Yellow	43521	43521_0_g	129.5	52.553531	13.2403329	1473907.1	6900836.40
Yellow	43522	43521_1_g	555.2	52.554428	13.2415509	1474042.70	6901000.7
Yellow	43523	43521_2_g	12.6	52.55128	13.2476131	1474717.5	6900424.4
Yellow	43524	43521_3_g	39.9	52.551192	13.2477951	1474737.80	6900408.3
Yellow	43525	43521_4_g	66.6	52.550957	13.2482402	1474787.4	6900365.3
Yellow	43526	43521_5_g	137.8	52.55038	13.2479827	1474758.7	6900259.6
Yellow	43527	43521_6_g	84.1	52.549542	13.246762	1474622.8	6900106.1
Yellow	43528	43521_7_g	88.8	52.548943	13.2460005	1474538	6899996.5
Yellow	43529	43521_8_g	207.2	52.549789	13.2433188	1474239.5	6900151.4
Yellow	435310	43521_09_g	352.2	52.550572	13.2442532	1474343.5	6900294.8
Yellow	435311	43521_10_g	90.2	52.552403	13.2405087	1473926.7	6900630
Yellow	435312	43521_11_g	89.1	52.553099	13.24128	1474012.6	6900757.3

**Table 9:** Overview new nodes and links

These nodes and lines were chosen to avoid traffic congestion of any kind, as well as allow pedestrians and cyclers to travel around the quarter safely. Also, the congested areas as different times, such as the school in the morning, are taken into consideration.

### 5.2.1.1 Network Code

The code is written in JAVA code is formatted in XML. The XML here is for simplicity and easy reading from all computer systems easily. XML stands for eXtensible Markup Language which is able to be self-descriptive and capable to store and move data. Therefore it does not require an extra software to decrypt or edit the code inside the file.

The Network code consists of two different parts.

- The nodes, which can be compared to specific points with valid coordinates.
- The links following the nodes, which are the connections between two or more different nodes.

Therefore there cannot be a link without already existing nodes in the code. It is absolutely crucial for the nodes to be stated before the links.

If we take the pink line as an example, the following overview offers the detailed parameters. The ID, x and y parameters are needed for the nodes code.

Color	ID	Link ID	distance to next (m)	lat	long	x	y
Pink	260405738	7465_0_ps	167.3				
Pink	74651	7465_0_p	269.1	52.554596	13.2381576	1473665	6901031.4
Pink	74652	7465_1_p	170.3	52.553099	13.24128	1474012.6	6900757.3
Pink	74653	7465_2_p	540.2	52.551913	13.2396841	1473834.9	6900540.2
Pink	74654	7465_3_p	84.1	52.548943	13.2460005	1474538	6899996.5
Pink	74655	7465_4_p	104.3	52.549542	13.246762	1474622.8	6900106.1
Pink	74656	7465_5_pg	18.30	52.548992	13.2480105	1474761.8	6900005.5
Pink	29706776						

**Table 10:** Overview pink line

To program a node the following is needed : `<node id="ID number" x="x-coordinate" y="y-coordinate" > </node>`. This can be seen on the figure below.

```

<nodes>
  <node id="74651" x="1473665.00" y="6901031.41" >
    </node>
  <node id="74652" x="1474012.55" y="6900757.31" >
    </node>

```

**Figure 28:** Pink nodes code

To connect node 1 with node 2 or node: 74651 and 74652: a link must be added. This needs the following parameters: `<link id="name for the link" from="node 1" to="node`

2" length="distance in meters" freespeed="allowed speed in m/s" capacity="cars capacity" permlanes="number of lanes" oneway="1" modes="modes of transport" > </link>. Here the speed of the car and the maximum allowed capacity is chosen depending on the location and the corresponding law for transport.

```

</link>
<link id="7465_0_p" from="74651" to="74652" length="269.1" freespeed="8.333333333333334"
capacity="150.0" permlanes="1.0" oneway="1" modes="car" > </link>

```

**Figure 29:** Pink links code



### 5.2.2 The Population

Since a residential Gartenfeld does not exist yet, a meeting with the senate administration allowed more insight about rough numbers based on statistics. Gartenfeld is expected to host 7400 residents, who on average get 629 guests a day. 223 retailers will be visited by 3764 shoppers and 1740 office workers will meet up with 435 other workers. In addition 418 trade workers will be expecting around 104 externals and 274 government and social workers will host 3239 visitors a day.

User Group	Amount	Visitors Amount
Residents	7400	629
Retailers	233	3764
Office workers	1740	435
Trade workers	418	104
Government and Social workers	274	3239

**Table 11:** Gartenfeld residents, workers and visitors per day

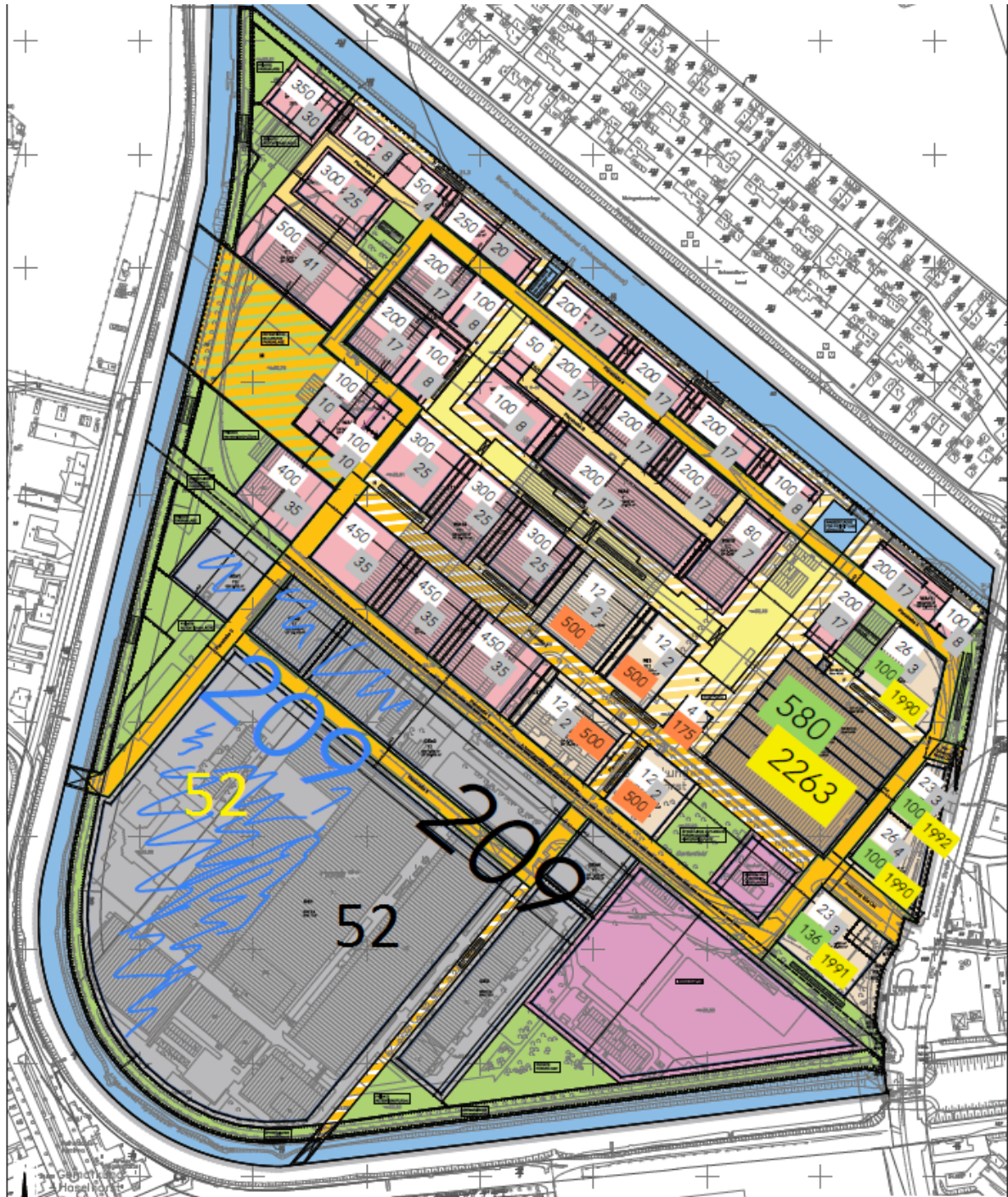
These people are to be distributed throughout the quarter in a reasonable manner. Keeping in mind where it makes sense to locate the residents and workers and when to place them together. This is a crucial point for the next step of the MATSim simulation, programming "The Population".

The allocation of the residents is set on the other side of the free way, allowing the retailers and shops to have the edge of the quarter. This is done for two reasons, firstly the residents are positioned at the green side of the quarter, to allow for a more quite, car-free life. The second reason is to allow the shops to be easy accessible to neighbouring quarts. The stops are set on the nodes mentioned in [subsubsection 5.2.1](#) and adjusted to the optimum based on the design of Berlin.

Stop	Line	X	Y
1	Pink	1473665	6901031.4
2	Pink	1473834.89	6900540.2
3	Pink	1474538.03	6899996.5
4	Pink	1474622.8	6900106.1
1	Orange	1473755.88	6900423.2
2	Orange	1474165.72	6900086.4
1	Yellow	1473907.12	6900836.4
2	Yellow	1474042.7	6901000.7
3	Yellow	1474717.54	6900424.4
4	Yellow	1474622.8	6900106.1
5	Yellow	1474538.03	6899996.5
6	Yellow	1474622.8	6900106.1
7	Yellow	1473926.69	6900630

**Figure 30:** Linestops

The distribution of people in 12 Gartenfeld is shown on :



**Table 12:** Distribution of Gartenfeld residents, workers and visitors



The numbers in the white fields represent the number of residents, while the numbers with the grey background are their corresponding visitors. This was calculated, through dividing the 629 number of expected guests by the number of 7400 residents, resulting in 0.0085 visitors per resident a day as mentioned in Table 11. This amounts to about a visitor every two weeks, which is the German standard equivalent. These people were then submitted to a specific stop on a specific line, assuming that it would be the closest point for them to go to. However, the number of a line stop user is not equivalent to the total number of people living closest to that stop. Assumptions are set in accordance to the Berlin equivalent statistics in different zones.

Spandau, which is where Gartenfeld is located withing Berlin and Berlin's city center were compared in accordance with the data extracted from the Berlin statistics [57]. In Table 13 the percentage of a mode transport usage in each of these areas is presented:

Mode of transport	Spandau	City Center
Personal vehicle	44%	22%
On foot	26%	35%
Bicycle	8%	14%
Public Transportation	22%	29%

**Table 13:** Gartenfeld residents, workers and visitors per day

Furthermore, according to the Berlin statistics the amount of bike riders increases by 15% in the Summer and is decreased from the public transportation users. This results in the S-Bahn and U-Bahn being very full in the Winter and empty in the Summer, since they cannot change supply according to the season. In Gartenfeld however, this will not be the case, since the planing of the vehicles usage will be flexible and based on the demand. For that reason different assumptions are set in the summer and in the winter. It must be considered, that residents, who live close to the slow yellow line, might choose to walk to the next pink fast line stop to get to their destination. These are defined as indirect residents on the Table 14.

Assumption	Summer	Winter
Residents on foot	30%	30%
Indirect residents on foot	20%	20%
Transport by bicycle	30%	15%
Indirect residents use yellow line	25%	35%
Indirect residents use pink line	35%	30%
Residents use pink line	40%	55%
Visitors use lines	50%	75%

**Table 14:** Gartenfeld residents, workers and visitors per day

Whereas all trade workers are expected use the orange time in all seasons, since it is further away from the freeway. And all the other workers and their visitors are expected to use the lines at all times.

Based on these assumptions a calculation for each line stop is made in order to be able to better understand the flow of transportation through Gartenfeld.

Stop	Line	Residents	Guests	Residents indirect	Guests	Workers	Clients
1	Pink	1200	101	1150	112	0	0
2	Pink	2000	165	865	71	0	0
3	Pink	97	43	865	71	0	0
4	Pink	49	6	0	0	1052	8236
1	Orange	0	0	0	0	209	52
2	Orange	0	0	0	0	209	52
1	Yellow	0	0	2880	254	0	0
2	Yellow	0	0	2015	183	0	0
3	Yellow	526	45	1730	142	100	1990
4	Yellow	0	0	0	0	916	6245
5	Yellow	23	3	0	0	1052	8236
6	Yellow	0	0	0	0	2175	0
7	Yellow	0	0	2880	254	0	0

**Table 15:** Amount of line stops users

Another very important aspect to consider is the peak times and rush stops. The hours are set for residents and workers, defined as standards with a daily routine. They are expected to be 06:00-9:00 in the morning and 16:00-18:00 in the afternoon. These are considered to be the heaviest rotations for the vehicles with the highest amount of users. Furthermore, exit and entry points for Gartenfeld are considered to be rush stops. These are shown on 15 highlighted in green. Random users are people who do not live or work in Gartenfeld and thus are do not have a fixed schedule.

Stop	Total standard	Total random
1	2350	213
2	2865	236
3	962	114
4	1101	8242
1	209	52
2	209	52
1	2880	254
2	2015	183
3	2356	2177
4	916	6245
5	1075	8239
6	2175	0
7	2880	254

**Table 16:** Total users

Resulting in the following total number of users in peak times for different stops. Here st stands for standard and r for random.

Stop	peak summer st	peak winter st	peak summer r	peak winter r
1	883	1005	107	160
2	1103	1360	118	177
3	342	313	57	86
4	546	816	4121	654
1	105	105	26	26
2	105	105	26	26
1	720	1008	127	191
2	504	705	92	137
3	693	970	1089	1633
4	458	687	3123	4684
5	535	802	4120	6179
6	1088	1631	0	0
7	720	1008	127	191

Table 17: Total users

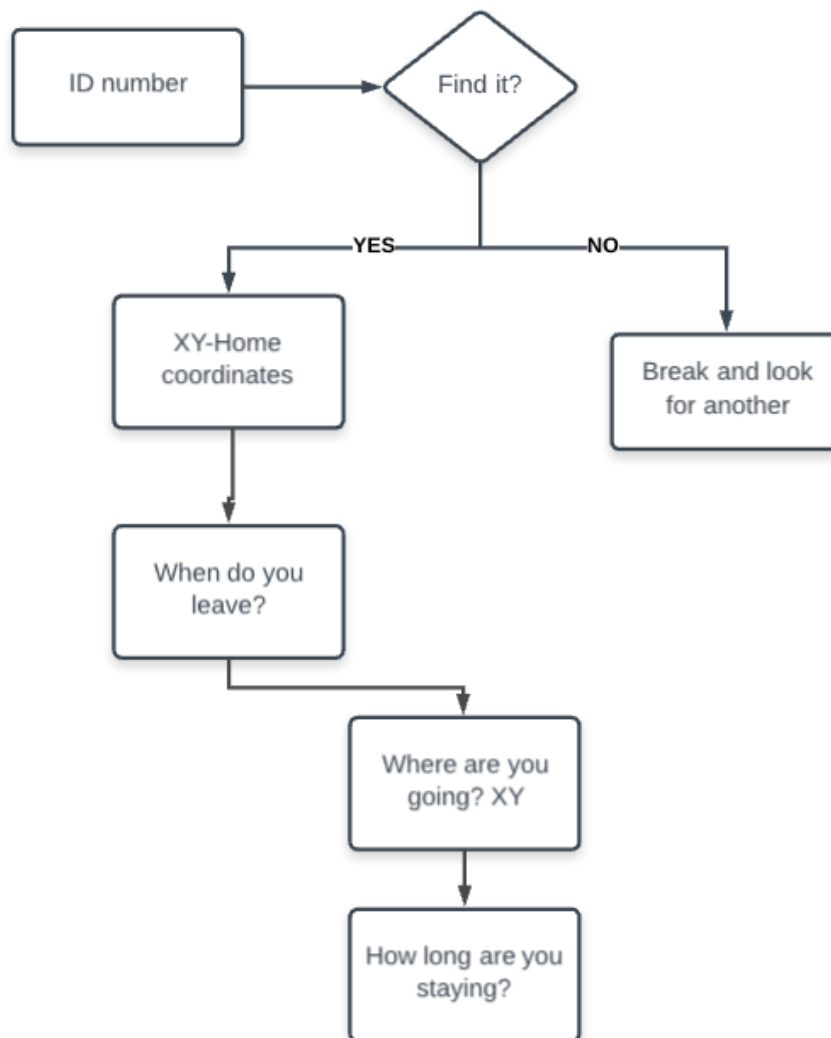
This will be programmed and explained in the following 5.2.2.1.

#### 5.2.2.1 Population Code

For that each person will be programmed on their own with the following parameters:

- ID: unique number for every person
- Home coordinates: XY-coordinates and link
- Time to leave home: HH:MM format
- Mode of transport: car, train, bike, etc..
- Preferred way to work: links
- Work coordinates: XY-coordinates and link
- Time spent at work: HH:MM format
- Usual time needed to commute: HH:MM format

Each piece of information is very important, to allow a real traffic situation to be simulated. Depending on the times and coordinates the needed amount of vehicles can be calculated, while the routes help determine the best way to go. The usual time allows the program to have a reference and be able to calculate how it is performing in comparison to a standard bus line. To code a person and their habits, the following 31 is shown to present it.



**Figure 31:** Population code

### 5.2.3 Configuration

The configuration is the glue that holds all of the factors together. It is equivalent to the main code in a program. It sets all the boundary conditions and knows where to find its network and population. Moreover the number of iteration needed is set in this code. This number, allows MATSim to run the simulation a number of times each time learning from the one before. Generally 10 iterations is sufficient.

Also, it is crucial to define to what extent a vehicle should modify its behavior. Vehicles will be assigned to a specific route and since the vehicles should not be modifying their route all the time. However, they are expected to learn from their mistakes and not repeat them. Therefore vehicles will be allowed a 10% modification factor whereas 90% will be following the normal route.

How the vehicle learns from its behaviour depends on its score. The score will be given on a point system that is defined in the configuration code. For late arriving, early departure, extra travelling, waiting and performing some points will be given or deducted. This point system can be seen in [32](#) This is followed by the priority of the activity, which is given to home and work in that order. Also showing the duration of work according to the German standards.

This configuration code is everything a person needs to know about the learning algorithm. It can be modified, extended depending on the wanted outcome. The weighted points and priorities here are defined as a personal preference. Applying -18 points for late departure, is based on the German appreciation of punctuality. This will not be given the same importance everywhere else.

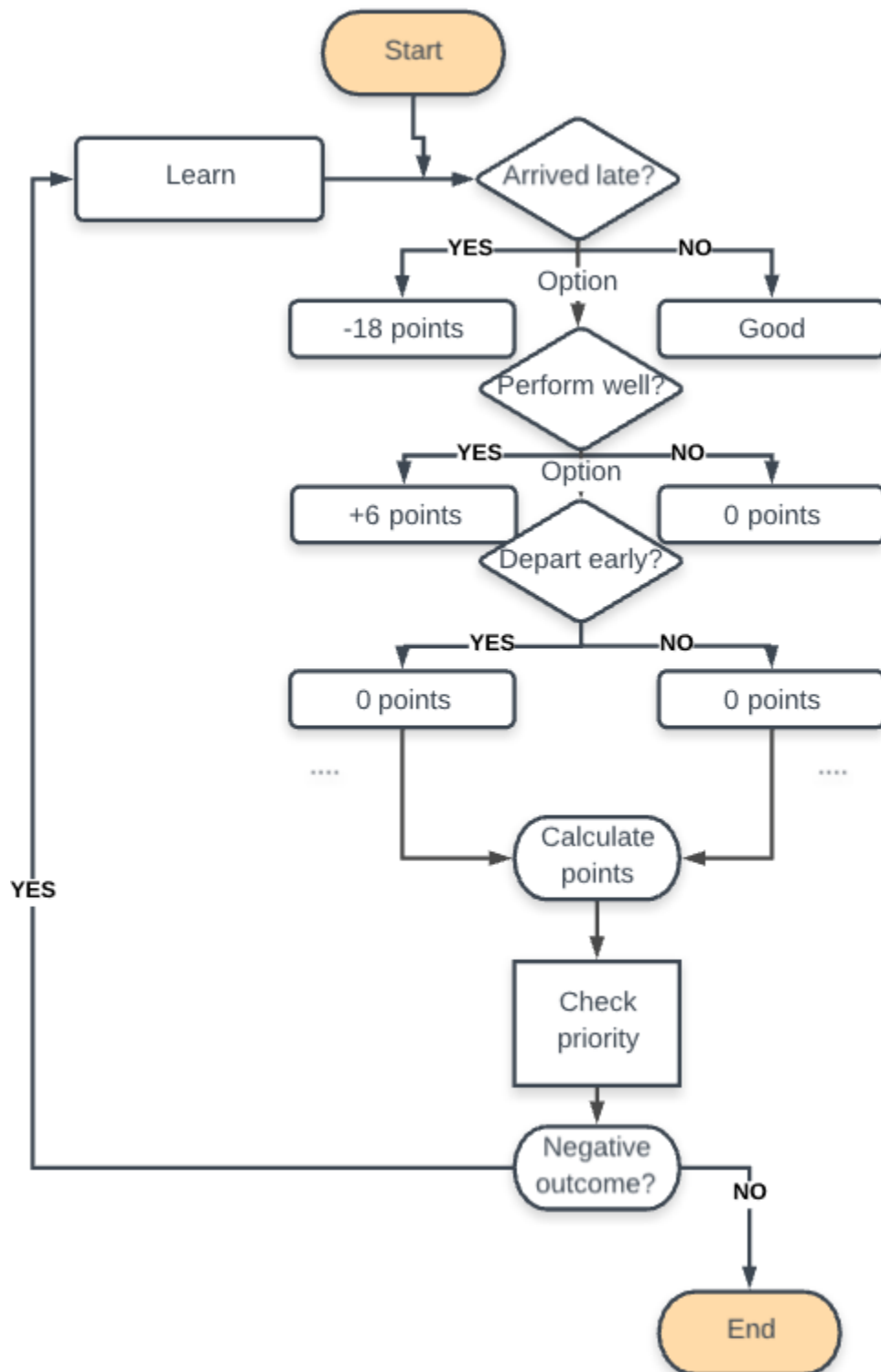


Figure 32: Configuration code

The final result on MATSim can be seen in Figure 33. Here the Green arrows represent the vehicles and the white lines represent the streets of Gartenfeld and the surrounding area.



**Figure 33:** Final result MATSim viewed in VIA

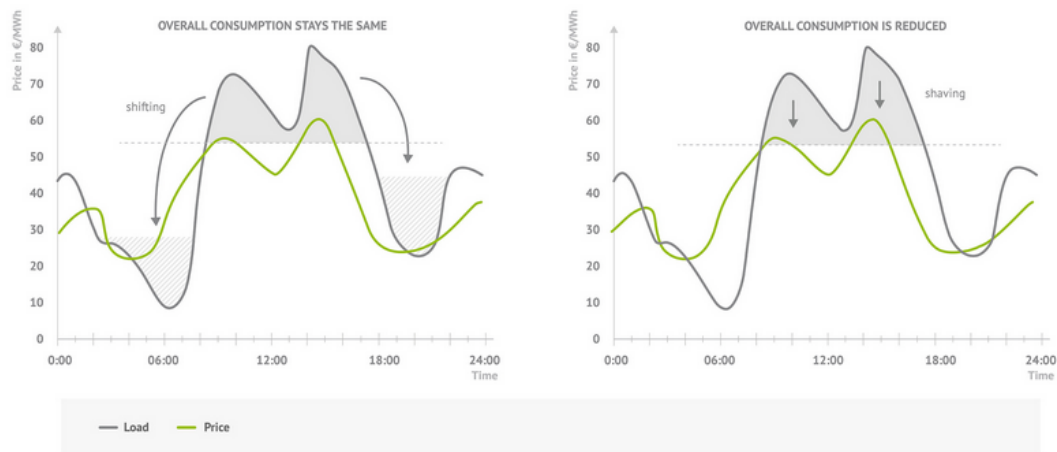
## 6 Results

### 6.1 The Technical Potential

The technical potential of this autonomous vehicles fleet cannot be calculated based on real consumption in Gartenfeld, since there is no data. However an estimation based on what is anticipated to happen in the near future and compared to existing plans.

The potential will be based on Demand Side Management (DSM) concept. This is the the initiative run under the Integrated Resource planing idea [62]. This the ideology that enables controlling the electrical load rather than the generation. Since the generation is soon to be based on fluctuating renewable in the future, DSM is very necessary.

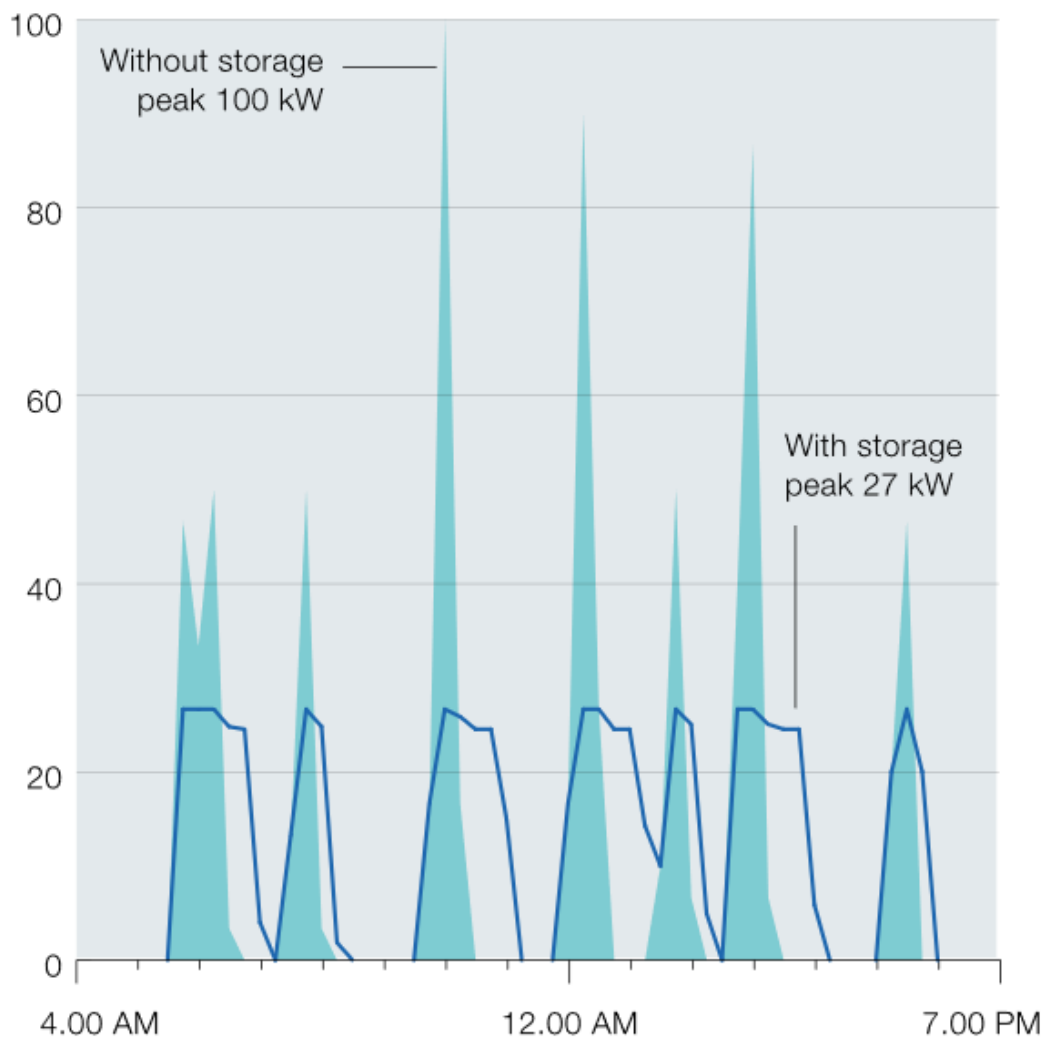
There are two types of DSM, load shifting and peak shaving. Load shifting is the act of delaying a specific load to a different time. This is considered to be a short term solution, that only buys some time. The long term solution is peak shaving. This literally shaves the peak on a definite basis. Both types require smart meters, energy efficient products and awareness spreading. The difference between the two is shown on 34 [63].



**Figure 34:** Load shifting vs Peak shaving [63]

To make that happen, initiatives from individuals as well as governments is required. EVs are anticipated to be an essential part of DSM, by charging and discharging the vehicles according to the load curve. If done properly, these vehicles are estimated to reduce 66% of Gartenfeld's extra storage units. These storage units are essentially for back-ups and protection. This estimation is based on McKinsey's article "How battery storage can help charge the electric-vehicle market" [64].





**Figure 35:** EV storage and electrical demand [64]

This enormous upgrade is doable, if both the residents and the politicians of Gartenfeld are willing to collaborate. Generators, which are mostly run on diesel or gas and are there to support the grid to provide security of supply to the users. Since electricity is considered a basic human right in Germany, losing it will result in a huge fine to the electricity providers. The levelized cost of electricity therefore includes the cost for supplied extra storage. It is no surprise that only 25% of the final electricity price is the wholesale price. Such a system could on the long run reduce the cost of electricity, provided it can handle the storage and shorten the needed cable for the distribution of electricity. If every quarter could take on this system, it will enable a decentralized electrical system, one that does not require as much back ups and unnecessary costs.

## 6.2 The Economical Potential

To analyze the economical potential of the autonomous fleet, the total cost per 10 years is calculated. These costs consist of capital cost shown in Table 19, which is only paid once. And variable cost, which is paid annually shown in Table 21.

To calculate the total running cost for 10 years, some assumptions must be made for each line. This includes the total distance with an estimate of waiting time and marginal error. Therefore, although all vehicles are able to drive at 50km/h, the time they need to stop and accelerate are taken into consideration modifying the average speed. These basic information are shown in Table 18.

	Pink line	Orange line	Yellow line
Distance/round	5.855km	3.600km	2.355km
Average speed	25km/h	25km/h	11km/h
Waiting time	3min	1min	7min
Time per round	17min	10min	20min
Vehicles/5min interval	4	2	4

**Table 18:** Lines information

Based on this, the amount of vehicles are calculated, considering their technical limitations. Allowing two storage units to be distributed, one at the beginning of the pink line, which intersects with the yellow line. And another at the beginning of the orange line entering Gartenfeld. The ratio of electric vehicles to normal vehicles is 0.8. This means for Gartenfeld, that 10 Diesel busses will be needed at all times. 2 extra buses will be there for fueling and maintenance and back up. With the ratio 1:0.8 that results in 15 needed electric driven vehicles. The HEAT vehicles will be handled similar to the electric bus. Whereas the HEAT battery is smaller and thus requires more time, however the coding maintenance will require a little more so an equal amount is assumed.

Cost	Autonomous fleet	12m Bus	12m Electric Bus
Cost/Vehicle	260.000€	250.000€	600.000€
# of Vehicles	15	10	15
Total cost	3.900.000€	2.500.000€	9.000.000€
Passengers/vehicle	16	70	70
Cost/vehicle-person	15.625€	3.572€	8.572€

**Table 19:** Capital cost comparison

Based on this data alone, the autonomous vehicle seems to be the most expensive. This is the reason a lot of cities are reluctant to take on the transition. This cost is a one time purchase for the vehicles and is only paid again, when the vehicle has to be replaced. It is anticipated that autonomous vehicles will be able to software update and will not have to be replaced as much as normal vehicles.

Table 21 below, examines the annual costs of the vehicles. These numbers are estimated based on the prices nowadays. These vary and are expected to grow within the following 10 years, however this thesis will be taking an approximate. The reason behind this is, that the overall cost difference will not differ that much and this is the measured outcome. An estimation of 3 drivers per vehicle is assumed. Dividing 24h per day on the 8h working day in Germany. Assuming a 5min interval, 288 rounds per day per line will be made, resulting to 105.120 rounds per year per line. An approximated 3400km are to be driven per day for all lines. With a calculated 0.30 €/kWh and 1.30 €/l. All estimations were based on assumptions from [65] [66] [67] [68] [69] [70] [71] [72].

Cost	Autonomous fleet	12m Bus	12m Electric Bus
Staff wage/h	0€	15€	15€
Needed drivers	0	30	30
Needed staff	6	3	3
Staff wage/year	172.800€	950.400€	950.400€
Staff insurance/year	43.800€	240.900€	240.900€
Fuel need/km	0.2kWh	0.25 Diesel	0.5kWh
Fuel cost/year	74.460€	403.325€	186.150€
Co2/km	0	0.23kg	0
Price CO2 / year	0	7.136 €	0
Total v-cost 10 years	2.910.600€	16.017.610€	13.774.500€

**Table 20:** Variable cost comparison

Adding these together results in the following total cost for 10 years:

Cost	Autonomous fleet	12m Bus	12m Electric Bus
Cost for 10 years	6.810.600€	18.517.610€	22.774.500€

**Table 21:** Variable cost comparison

### 6.3 The Environmental Potential

Regardless the outcome of the economical analysis, there is an important factor that cannot be measured in money. The habitability of the earth.

The world has already seen its first challenges resulted from climate change. Multiple countries have taken the initiative to actively reduce their CO<sub>2</sub> emissions. Others have realised that this is not enough and aimed towards investing in Carbon Capture and Storage (CCS). Additionally billions of Euros have been invested into integrating renewable energy generation into the grid and encouraging Demand Side Management. This is all being done to stay under the 450ppm in CO<sub>2</sub> equivalent Green House Gas emissions. By staying below 450ppm, the world has a 50% chance to only increase the average global temperature by 2°C. Road traffic alone is responsible for about 30% of the total CO<sub>2</sub> emissions. Figure 36 shows the expected emissions depending on the action.

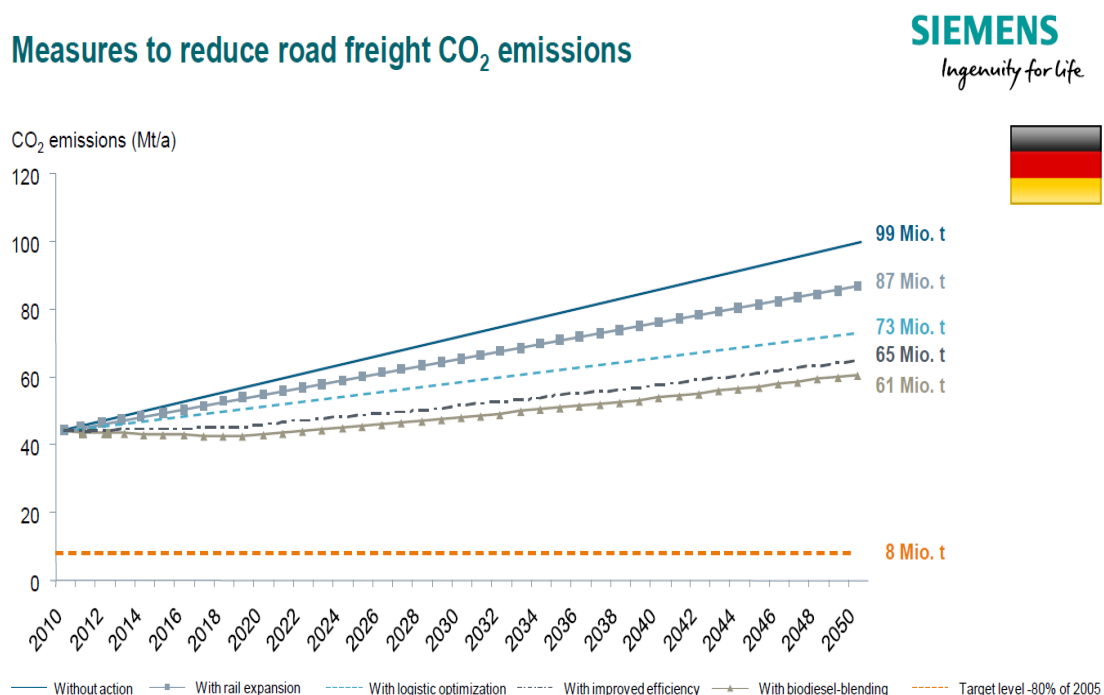


Figure 36: CO<sub>2</sub> targets [22]

The only way to achieve the targeted 8Mio. t is to completely eliminate all fossil fueled vehicles and make sure that the electric vehicles are charged via renewable energy sources. The autonomous fleet here offers more flexibility and calculated risks. If this system would be applied worldwide, enormous decrease of emissions will be seen as a result to the fluid integration of renewable. As well as the elimination of combustion vehicles and reduction of needed vehicles to 10% in comparison to today's.

## 7 Conclusion

Mobility is expected to have a drastic change on the world. With Germany being a leading country of car manufacturers, this could be challenging. Nonetheless, Smart Mobility will have to rise, enabling support to the electrical grid on the one hand and promote citizen's life on the other hand. Autonomous vehicles together with artificial intelligence promise a future with stress free transportation.

This thesis analyzed the potential of such an autonomous fleet in a specific urban quarter "Gartenfeld" in Berlin, Germany. This quarter is chosen for its ideal location, values and emission-free vision. It is also a quarter that is in its constructing phase and will only be habitable in the following 10 years. This period of time is sufficient for the development of the autonomous vehicles and the appropriate preparation for the citizens. It will be easier for them to use a new system, if they are in a new place, where they are not acquainted to anything yet.

Gartenfeld's streets and residents were programmed in MATSim, a multi agent simulation tool designed for transportation. Through coding and iteration, the best route was calculated and modified. This resulted to three level 4 autonomous vehicles lines getting their citizens to the closest metro station, leaving each stop every 5 minutes. The amount of needed vehicles was then used for an economical analysis and compared to a diesel 12m bus and an electric bus. This analysis showed positive results for the new fleet and was concluded with an economical analysis. This proved that a significant decrease of CO<sub>2</sub> emissions is expected through this system. In conclusion, the technical, economical and environmental analysis resulted to a positive outcome. This system is based on realistic statistics and is ready to be implemented given the proper adjustments. Such a system could help the world decarbonize in the future and thus improve the quality of life. It will enable swift and easy mobility throughout cities and can be adapted everywhere. It will also avail new job positions such as the traffic coder, while existing ones such as the bus/taxi driver will be obsolete. However, this is the circle of life and only the fittest- and in our case the smartest- will survive.

## 8 Future work

This thesis analyzes the potential of automated transport systems in the urban quarter Gartenfeld in Berlin. The same methodology and steps can be applied to cover Berlin as a whole city. Analyzing and understanding the potential of such an implementation of autonomous vehicles can help the German transport system massively. Starting with the economical savings on the long run, and eventually relieving the burden of having to decrease CO2 emissions on the roads. The same system could subsequently be utilized to cover Germany and then European.

In the future the implementation of the autonomous transport system should be taken into account while designing a new city. The vehicle should be considered not only a part of the transportation system, but also a part of the electrical grid. Enabling a safe and environmentally friendly commute while guaranteeing stability of the electrical distribution grid. The need of large battery storage will not be needed, as the vehicles will be acting as a big battery divided into small pieces. This enables the grid to be acting in a more of a decentralized approach and will not require huge amount of energy to be flowing through the cables for hundreds of kilometers and allowing peak shaving of the residential load profile. It will also benefit Transmissions system operators, who will not have to contact the Balance Responsible Party to settle the electrical equilibrium. Moreover, the Energy Market will be more stabilized and Demand Side Management can take its form in the shape of a public automated vehicle. Allowing better quality of life for the resident, safe regulation of the electrical flow for the government to and a greener environment. Another step could be introducing different sizes of vehicles allowing this transport system to completely eliminate delivery cars and trucks. The system could take advantage of peak and non-peak hours and smartly avoid traffic. Introducing 5G communication together to the existing Vehicle to everything communication allows a Smart City to grow and properly and efficiently.

A further step could be to introduce luxurious vehicles and eliminating the taxi. Enabling the customer to choose to go for a fancy car for a premium price. This is very important to maintain and engage people from different backgrounds and societies.

The most important step for any project to go forward isto educate the citizens about the benefits of the project. A person is reluctant to change until they are convinced of the benefits and gains. If a government fails to convey the message of the importance of being environmentally friendly, the citizens will be the hardest party to get on board. No matter how complicated the design and the structure of the city is and no matter how environmentally friendly and pretty it is, there will be no Smart City without Smart Citizens. Education must be one of the most important steps in every government's agenda.

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## A Configuration Code :

```

<?xml version="1.0"?>
<!DOCTYPE config SYSTEM "http://www.matsim.org/files/dtd/config_v2.dtd" >
-<config>
-<module name="global">
<param name="randomSeed" value="4711"/>
<param name="coordinateSystem" value="Atlantis"/>
</module>
-<module name="network">
<param name="inputNetworkFile" value="network.xml"/>
</module>
-<module name="facilities">
<param name="inputFacilitiesFile" value="facilities.xml"/>
<param name="facilitiesSource" value="fromFile"/>
</module>
-<module name="plans">
<param name="inputPlansFile" value="plansSummer.xml"/>
</module>
-<module name="controler">
<param name="outputDirectory" value="./output"/>
<param name="firstIteration" value="0"/>
<param name="lastIteration" value="10"/>
</module>
-<module name="qsim">
<!-- "start/endTime" of MobSim (00:00:00 == take earliest activity time/ run as long
as active vehicles exist) -->
<param name="startTime" value="00:00:00"/>
<param name="endTime" value="00:00:00"/>

```

```

<param name="snapshotperiod" value="00:00:00"/>
<!-- 00:00:00 means NO snapshot writing -->
</module>
-<module name="planCalcScore">
  <param name="learningRate" value="1.0"/>
  <param name="BrainExpBeta" value="2.0"/>
  <param name="lateArrival" value="-18"/>
  <param name="earlyDeparture" value="-0"/>
  <param name="performing" value="+6"/>
  <param name="traveling" value="-6"/>
  <param name="waiting" value="-0"/>
  <param name="activityType0" value = "h" / >
  <!-- home -->
  <param name="activityPriority0" value = "1" / >
  <param name="activityTypicalDuration0" value = "12 : 00 : 00" / >
  <param name="activityMinimalDuration0" value = "08 : 00 : 00" / >
  <param name="activityType1" value = "w" / >
  <!-- work -->
  <param name="activityPriority1" value = "1" / >
  <param name="activityTypicalDuration1" value = "08 : 00 : 00" / >
  <param name="activityMinimalDuration1" value = "06 : 00 : 00" / >
  <param name="activityOpeningTime1" value = "07 : 00 : 00" / >
  <param name="activityLatestStartTime1" value = "09 : 00 : 00" / >
  <param name="activityEarliestEndTime1" value = "" / >
  <param name="activityClosingTime1" value = "18 : 00 : 00" / >
</module>
-<module name="strategy">
  <param name="maxAgentPlanMemorySize" value="5"/>
  <!-- 0 means unlimited -->

```

```
<param name="ModuleProbability1" value = "0.9" / >  
<param name="Module1" value = "BestScore" / >  
<param name="ModuleProbability2" value = "0.1" / >  
<param name="Module2" value = "ReRoute" / >  
</module>  
</config>
```

## B Network Code :

```
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-<network>
<!-- =====
-->
-<nodes>
<node y="6901031.41" x="1473665.00" id="74651"> </node>
<node y="6900757.31" x="1474012.55" id="74652"> </node>
<node y="6900540.24" x="1473834.89" id="74653"> </node>
<node y="6899996.54" x="1474538.03" id="74654"> </node>
<node y="6900106.12" x="1474622.80" id="74655"> </node>
<node y="6900005.53" x="1474761.78" id="74656"> </node>
<node y="6900243.08" x="1473456.82" id="6726431"> </node>
<node y="6900214.19" x="1473576.46" id="6726432"> </node>
<node y="6900423.18" x="1473755.88" id="6726433"> </node>
<node y="6900086.39" x="1474165.72" id="6726434"> </node>
<node y="6899577.82" x="1473745.16" id="6726435"> </node>
<node y="6900836.40" x="1473907.12" id="43521"> </node>
<node y="6901000.65" x="1474042.70" id="43522"> </node>
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```



```

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<node y="6900757.31" x="1474012.55" id="435212"> </node>
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<node y="6898046.8822925035" x="1472948.087816294" id="3964527981"> </node>
<node y="6898111.9467726955" x="1472967.334956252" id="3964527982"> </node>
<node y="6898080.357032403" x="1473567.892477133" id="565514285"> </node>
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<!-- =====
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<link id="100836195<sub>0</sub>" modes = "car" oneway = "1" permlanes = "1.0" capacity = "300.0" freespeed = "4.166666666666667" length = "23.262272243347034" to = "1165344899" from = "1165344921" >< /link >

<link id="100836195<sub>0r</sub>" modes = "car" oneway = "1" permlanes = "1.0" capacity = "300.0" freespeed = "4.166666666666667" length = "23.262272243347034" to = "1165344921" from = "1165344899" >< /link >

<link id="100836196<sub>0</sub>" modes = "car" oneway = "1" permlanes = "1.0" capacity = "300.0" freespeed = "8.333333333333334" length = "13.077027428411057" to = "1408789996" from = "1165344886" >< /link >

<link id="4537628<sub>0</sub>" modes = "car" oneway = "1" permlanes = "1.0" capacity = "1000.0" freespeed = "13.888888888888889" length = "7.444721270843123" to = "6294209367" from = "1396446724" >< /link >

<link id="4537628<sub>0r</sub>" modes = "car" oneway = "1" permlanes = "1.0" capacity = "1000.0" freespeed = "13.888888888888889" length = "7.444721270843123" to = "1396446724" from = "6294209367" >< /link >

<link id="4537628<sub>1</sub>" modes = "car" oneway = "1" permlanes = "1.0" capacity = "1000.0" freespeed = "13.888888888888889" length = "120.51628319603068" to = "1124732028" from = "6294209367" >< /link >

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<link id="45376281r" modes = "car" oneway = "1" permlanes = "1.0" capacity = "1000.0" freespeed =  
"13.888888888888889" length = "120.51628319603068" to = "6294209367" from = "1124732028" >  
/link >  
</links>  
  
<!-- =====>  
->  
</network>
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## C Plans Code :

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<?xml version="1.0"?>
<!DOCTYPE plans SYSTEM "http://www.matsim.org/files/dtd/plans_v4.dtd" >
-<plans xml:lang="de-CH">
-<person id="1">
-<plan>
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"h" / >
-<leg mode="car">
<route>74651 74652 74653 74654</route>
</leg>
<act link="1258132170" y = "6899486.8613851" x = "1474958.8183826457" type = "w" dur =
"08 : 00" / >
-<leg mode="car">
<route> </route>
</leg>
<act link="1258132170" y = "6899486.8613851" x = "1474958.8183826457" type = "w" dur =
"00 : 30" / >
-<leg mode="car">
<route>74654 74653 74652 74651</route>
</leg>
<act link="74650p" y = "6901031.41" x = "1473665" type = "h" / >
</plan>
</person>
-<person id="2">
-<plan>
<act endtime = "05 : 04" link = "74650p" y = "6901031.41" x = "1473665" type =
"h" / >
-<leg mode="car">

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<route>74651 74652 74653 74654</route>
</leg>
<act link="1258132170" y = "6899486.8613851" x = "1474958.8183826457" type = "w" dur =
"08 : 00" / >
-<leg mode="car">
<route> </route>
</leg>
<act link="1258132170" y = "6899486.8613851" x = "1474958.8183826457" type = "w" dur =
"00 : 30" / >
-<leg mode="car">
<route>74654 74653 74652 74651</route>
</leg>
<act link="74650p" y = "6901031.41" x = "1473665" type = "h" / >
</plan>
</person>
-<person id="3">
-<plan>
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"h" / >
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<route>74651 74652 74653 74654</route>
</leg>
<act link="1258132170" y = "6899486.8613851" x = "1474958.8183826457" type = "w" dur =
"08 : 00" / >
-<leg mode="car">
<route> </route>
</leg>
<act link="1258132170" y = "6899486.8613851" x = "1474958.8183826457" type = "w" dur =
"00 : 30" / >
-<leg mode="car">

```

```

<route>74654 74653 74652 74651</route>
</leg>
<act link="74650p" y = "6901031.41" x = "1473665" type = "h" / >
</plan>
</person>
-<person id="4">
-<plan>
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"h" / >
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</leg>
<act link="1258132170" y = "6899486.8613851" x = "1474958.8183826457" type = "w" dur =
"08 : 00" / >
-<leg mode="car">
<route> </route>
</leg>
<act link="1258132170" y = "6899486.8613851" x = "1474958.8183826457" type = "w" dur =
"00 : 30" / >
-<leg mode="car">
<route>74654 74653 74652 74651</route>
</leg>
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</plan>
</person>
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-<plan>
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"h" / >
-<leg mode="car">

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<route>74651 74652 74653 74654</route>
</leg>
<act link="1258132170" y = "6899486.8613851" x = "1474958.8183826457" type = "w" dur =
"08 : 00" / >
-<leg mode="car">
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</leg>
<act link="1258132170" y = "6899486.8613851" x = "1474958.8183826457" type = "w" dur =
"00 : 30" / >
-<leg mode="car">
<route>74654 74653 74652 74651</route>
</leg>
<act link="74650p" y = "6901031.41" x = "1473665" type = "h" / >
</plan>
</person>
-<person id="34">
-<plan>
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"h" / >
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</leg>
<act link="1258132170" y = "6899486.8613851" x = "1474958.8183826457" type = "w" dur =
"08 : 00" / >
-<leg mode="car">
<route> </route>
</leg>
<act link="1258132170" y = "6899486.8613851" x = "1474958.8183826457" type = "w" dur =
"00 : 30" / >
-<leg mode="car">

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```

<route>74654 74653 74652 74651</route>
</leg>
<act link="74650p" y = "6901031.41" x = "1473665" type = "h" / >
</plan>
</person>
-<person id="42">
-<plan>
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"h" / >
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<route>74651 74652 74653 74654</route>
</leg>
<act link="1258132170" y = "6899486.8613851" x = "1474958.8183826457" type = "w" dur =
"08 : 00" / >
-<leg mode="car">
<route> </route>
</leg>
<act link="1258132170" y = "6899486.8613851" x = "1474958.8183826457" type = "w" dur =
"00 : 30" / >
-<leg mode="car">
<route>74654 74653 74652 74651</route>
</leg>
<act link="74650p" y = "6901031.41" x = "1473665" type = "h" / >
</plan>
</person>
-<person id="49">
-<plan>
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"h" / >
-<leg mode="car">

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<route>74652 74653 74654</route>
</leg>
<act link="1258132170"y = "6898239.533250528"x = "1473007.0092227708"type =
"w"dur = "08 : 00" / >
-<leg mode="car">
<route> </route>
</leg>
<act link="1258132170"y = "6898239.533250528"x = "1473007.0092227708"type =
"w"dur = "00 : 30" / >
-<leg mode="car">
<route>74651 74652</route>
</leg>
<act link="74651p"y = "6900540.24"x = "1473834.89"type = "h" / >
</plan>
</person>
-<person id="50">
-<plan>
<act endtime = "05 : 15"link = "74651p"y = "6900540.24"x = "1473834.89"type =
"h" / >
-<leg mode="car">
<route>74652 74653 74654</route>
</leg>
<act link="1258132170"y = "6898239.533250528"x = "1473007.0092227708"type =
"w"dur = "08 : 00" / >
-<leg mode="car">
<route> </route>
</leg>
<act link="1258132170"y = "6898239.533250528"x = "1473007.0092227708"type =
"w"dur = "00 : 30" / >
-<leg mode="car">

```

```

<route>74651 74652</route>
</leg>
<act link="74651p" y = "6900540.24" x = "1473834.89" type = "h" / >
</plan>
</person>
-<person id="51">
-<plan>
<act endtime = "05 : 18" link = "74651p" y = "6900540.24" x = "1473834.89" type =
"h" / >
-<leg mode="car">
<route>74652 74653 74654</route>
</leg>
<act link="1258132170" y = "6898239.533250528" x = "1473007.0092227708" type =
"w" dur = "08 : 00" / >
-<leg mode="car">
<route> </route>
</leg>
<act link="1258132170" y = "6898239.533250528" x = "1473007.0092227708" type =
"w" dur = "00 : 30" / >
-<leg mode="car">
<route>74651 74652</route>
</leg>
<act link="74651p" y = "6900540.24" x = "1473834.89" type = "h" / >
</plan>
</person>
-<person id="196">
-<plan>
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"h" / >
-<leg mode="car">

```

```

<route>74651 74652</route>
</leg>
<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "03 : 30" / >
-<leg mode="car">
<route> </route>
</leg>
<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "00 : 43" / >
-<leg mode="car">
<route>74652 74653 74654</route>
</leg>
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"h" / >
</plan>
</person>
-<person id="197">
-<plan>
<act endtime = "07 : 06" link = "1258132170" y = "6898239.533250528" x = "1473007.0092227708" type =
"h" / >
-<leg mode="car">
<route>74651 74652</route>
</leg>
<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "03 : 30" / >
-<leg mode="car">
<route> </route>
</leg>
<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "00 : 43" / >
-<leg mode="car">
<route>74652 74653 74654</route>
</leg>

```

```

<act link="1258132170"y = "6898239.533250528"x = "1473007.0092227708"type =
"h" / >

</plan>

</person>

-<person id="198">

-<plan>

<act endtime = "07 : 09"link = "1258132170"y = "6898239.533250528"x = "1473007.0092227708"type =
"h" / >

-<leg mode="car">

<route>74651 74652</route>

</leg>

<act link="74651p"y = "6900540.24"x = "1473834.89"type = "w" dur = "03 : 30" / >

-<leg mode="car">

<route> </route>

</leg>

<act link="74651p"y = "6900540.24"x = "1473834.89"type = "w" dur = "00 : 43" / >

-<leg mode="car">

<route>74652 74653 74654</route>

</leg>

<act link="1258132170"y = "6898239.533250528"x = "1473007.0092227708"type =
"h" / >

</plan>

</person>

-<person id="199">

-<plan>

<act endtime = "07 : 12"link = "1258132170"y = "6898239.533250528"x = "1473007.0092227708"type =
"h" / >

-<leg mode="car">

<route>74651 74652</route>

</leg>

```



```

<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "03 : 30" / >
-<leg mode="car">
<route> </route>
</leg>
<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "00 : 43" / >
-<leg mode="car">
<route>74652 74653 74654</route>
</leg>
<act link="1258132170" y = "6898239.533250528" x = "1473007.0092227708" type =
"h" / >
</plan>
</person>
-<person id="200">
-<plan>
<act end_time = "05 : 00" link = "45888090" y = "6899486.8613851" x = "1474958.8183826457" type =
"h" / >
-<leg mode="car">
<route>26759289 3056455792 2558204876 33484092 1396422515 1396422517 28321261
74651 74652</route>
</leg>
<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "03 : 30" / >
-<leg mode="car">
<route> </route>
</leg>
<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "00 : 43" / >
-<leg mode="car">
<route>74652 74653 74654 28321261 1396422517 1396422515 33484092 2558204876 3056455792
26759289</route>
</leg>
<act link="45888090" y = "6899486.8613851" x = "1474958.8183826457" type = "h" / >

```

```

</plan>
</person>
-<person id="201">
-<plan>
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"h" / >
-<leg mode="car">
<route>26759289 3056455792 2558204876 33484092 1396422515 1396422517 28321261
74651 74652</route>
</leg>
<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "03 : 30" / >
-<leg mode="car">
<route> </route>
</leg>
<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "00 : 43" / >
-<leg mode="car">
<route>74652 74653 74654 28321261 1396422517 1396422515 33484092 2558204876 3056455792
26759289</route>
</leg>
<act link="4588809" y = "6899486.8613851" x = "1474958.8183826457" type = "h" / >
</plan>
</person>
-<person id="202">
-<plan>
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"h" / >
-<leg mode="car">
<route>26759289 3056455792 2558204876 33484092 1396422515 1396422517 28321261
74651 74652</route>
</leg>

```

```

<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "03 : 30" / >
-<leg mode="car">
<route> </route>
</leg>
<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "00 : 43" / >
-<leg mode="car">
<route>74652 74653 74654 28321261 1396422517 1396422515 33484092 2558204876 3056455792
26759289</route>
</leg>
<act link="45888090" y = "6899486.8613851" x = "1474958.8183826457" type = "h" / >
</plan>
</person>
-<person id="203">
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"h" / >
-<leg mode="car">
<route>26759289 3056455792 2558204876 33484092 1396422515 1396422517 28321261
74651 74652</route>
</leg>
<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "03 : 30" / >
-<leg mode="car">
<route> </route>
</leg>
<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "00 : 43" / >
-<leg mode="car">
<route>74652 74653 74654 28321261 1396422517 1396422515 33484092 2558204876 3056455792
26759289</route>
</leg>
<act link="45888090" y = "6899486.8613851" x = "1474958.8183826457" type = "h" / >

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</plan>
</person>
-<person id="245">
-<plan>
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"h" / >
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<route>26759289 3056455792 2558204876 33484092 1396422515 1396422517 28321261
74651 74652</route>
</leg>
<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "03 : 30" / >
-<leg mode="car">
<route> </route>
</leg>
<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "00 : 43" / >
-<leg mode="car">
<route>74652 74653 74654 28321261 1396422517 1396422515 33484092 2558204876 3056455792
26759289</route>
</leg>
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</plan>
</person>
-<person id="246">
-<plan>
<act endtime = "07 : 18" link = "45888090" y = "6899486.8613851" x = "1474958.8183826457" type =
"h" / >
-<leg mode="car">
<route>26759289 3056455792 2558204876 33484092 1396422515 1396422517 28321261
74651 74652</route>
</leg>

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```

<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "03 : 30" / >
-<leg mode="car">
<route> </route>
</leg>
<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "00 : 43" / >
-<leg mode="car">
<route>74652 74653 74654 28321261 1396422517 1396422515 33484092 2558204876 3056455792
26759289</route>
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<act link="45888090" y = "6899486.8613851" x = "1474958.8183826457" type = "h" / >
</plan>
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-<person id="247">
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"h" / >
-<leg mode="car">
<route>26759289 3056455792 2558204876 33484092 1396422515 1396422517 28321261
74651 74652</route>
</leg>
<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "03 : 30" / >
-<leg mode="car">
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</leg>
<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "00 : 43" / >
-<leg mode="car">
<route>74652 74653 74654 28321261 1396422517 1396422515 33484092 2558204876 3056455792
26759289</route>
</leg>
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</plan>
</person>
-<person id="248">
-<plan>
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"h" / >
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74651 74652</route>
</leg>
<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "03 : 30" / >
-<leg mode="car">
<route> </route>
</leg>
<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "00 : 43" / >
-<leg mode="car">
<route>74652 74653 74654 28321261 1396422517 1396422515 33484092 2558204876 3056455792
26759289</route>
</leg>
<act link="45888090" y = "6899486.8613851" x = "1474958.8183826457" type = "h" / >
</plan>
</person>
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-<plan>
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"h" / >
-<leg mode="car">
<route>26759289 3056455792 2558204876 33484092 1396422515 1396422517 28321261
74651 74652</route>
</leg>

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<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "03 : 30" / >
-<leg mode="car">
<route> </route>
</leg>
<act link="74651p" y = "6900540.24" x = "1473834.89" type = "w" dur = "00 : 43" / >
-<leg mode="car">
<route>74652 74653 74654 28321261 1396422517 1396422515 33484092 2558204876 3056455792
26759289</route>
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"h" / >
-<leg mode="car">
<route>26759289 3056455792 2558204876 33484092 1396422515 1396422517 28321261
74651 74652</route>
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